BBC

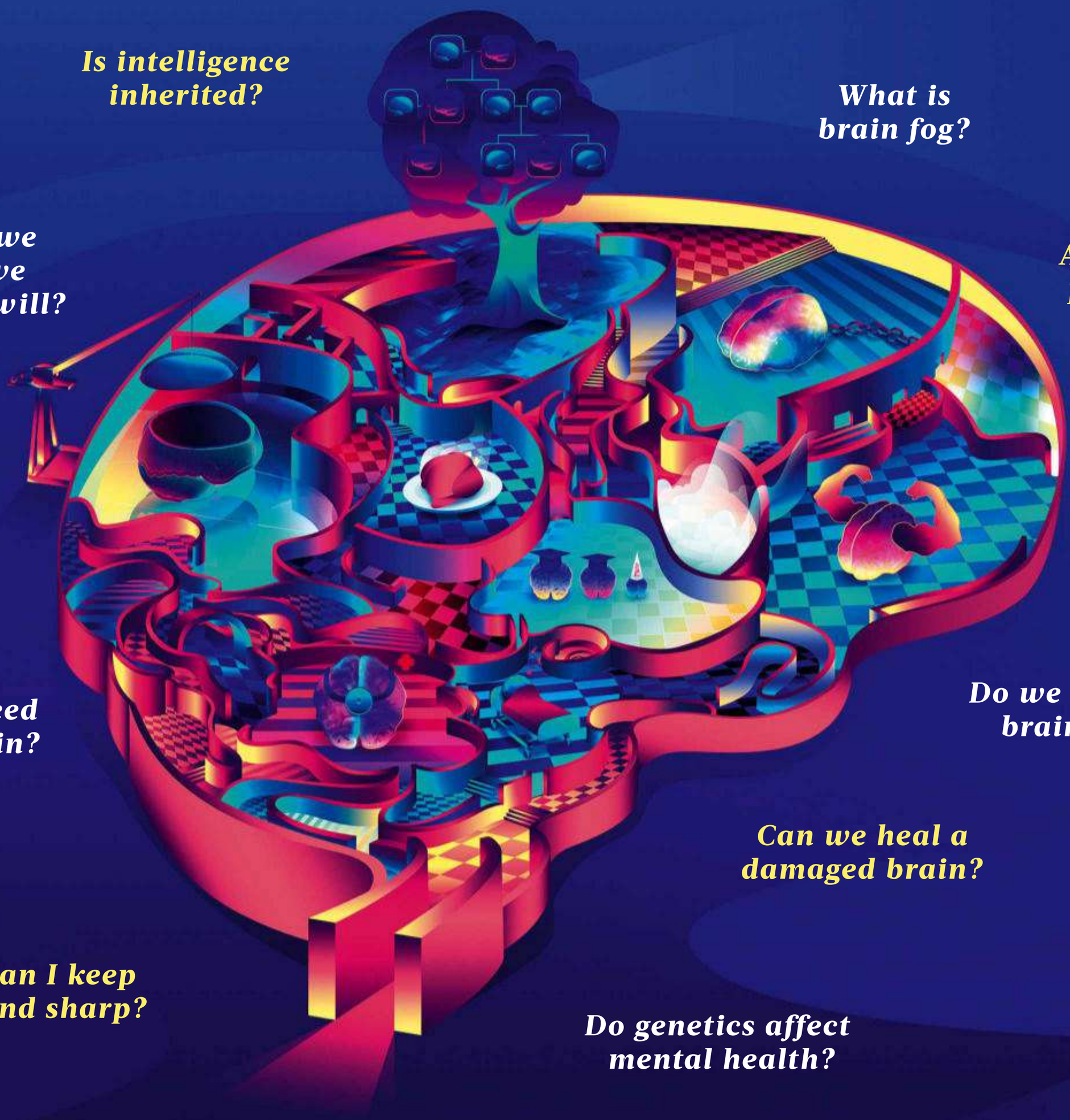
BRIAN COX: "I WANT TO LAUNCH BORIS INTO SPACE"

Science Focus

FOOD FOR THOUGHT

YOUR MYSTERIOUS BRAIN

9 mind-blowing questions about the most incredible object in the Universe



Is intelligence inherited?

What is brain fog?

Do we have free will?

Are coma patients awake?

Can I feed my brain?

Do we really have brain regions?

Can we heal a damaged brain?

How can I keep my mind sharp?

Do genetics affect mental health?

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Black holes
Is an ancient monster lurking in our Solar System?

Health
Michael Mosley on the power of deep breathing

Facebook
Are smart glasses a privacy nightmare?

Photography and videography can change us.
They change the way we feel.
Our understanding.

They change our hearts and minds.
They change the rules.

Testing the limits of our comfort zones.
Changing the way others see the world.
See themselves.

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Here's to the stories to come.

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FROM THE EDITOR

I touched a human brain once. At university, while I was studying psychology, a professor invited us to sign up for an extracurricular course on brain dissection: to study and understand the structures and geography of the thing we had been learning about. I signed up. It didn't seem like the kind of opportunity that came around often.

Before the first lesson, I was nervous and excited. To take part in any dissection is an honour. Bodies donated to science are a special gift, and so students are reminded that it's a privilege to be able to learn in this way. My brain was going to touch another brain with its hands and I was prepared for whatever revelation that might bring.

"Well, that's weirdly beige," was my first thought. Not very profound. Post-mortem, the preservation procedure turns a brain into what looks like a wet, brown blob of sculpted putty. The textbooks I had been learning from painted the brain as a thing of electricity, made of neurons that spark and create thoughts that spread like lightning through its structures. But sat in front of me on a lab bench, the brain had been cruelly robbed of its splendour.

Since then I've been obsessed with how the thing I saw creates the human experience. In recent years, neuroscience has been spectacular at piecing together how the brain sees the world, and uses the data it gathers to make decisions and form a sense of self. But the more we learn, the more we realise how much we don't understand. So this issue is dedicated to just that: the questions at the forefront of our study of the brain, and how this lump of tissue can create the most incredible thing in the Universe: a human mind.

Enjoy the issue!

Daniel Bennett, Editor

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ON THE BBC THIS MONTH...

The Lakes With Simon Reeve
Simon Reeve explores England's largest National Park: the Lake District. We meet the people (and wildlife) of Cumbria, traverse the expansive landscape, and learn about some of the threats to its inhabitants.
BBC Two
Check *Radio Times* for details

Our Family and Autism
With three young children diagnosed with autism, Paddy and Christine McGuinness set out to better understand the condition, speaking to leading paediatricians and child-development experts.
BBC One
Check *Radio Times* for details

This Thing Of Darkness
Fictional psychiatrist Dr Alex Bridges, played by Lolita Chakrabarti, is called in to take a forensic look at arson, stalking and the impact of trauma in the new series of this award-winning podcast.
BBC Radio 4 and BBC Sounds
From 11 Nov

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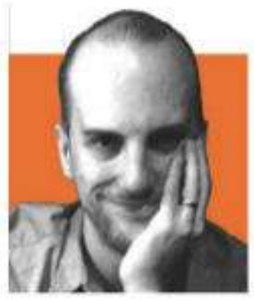

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CONTACT US

Advertising
Gino.DeAntonis@immediate.co.uk
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Letters for publication
reply@sciencefocus.com
Editorial enquiries
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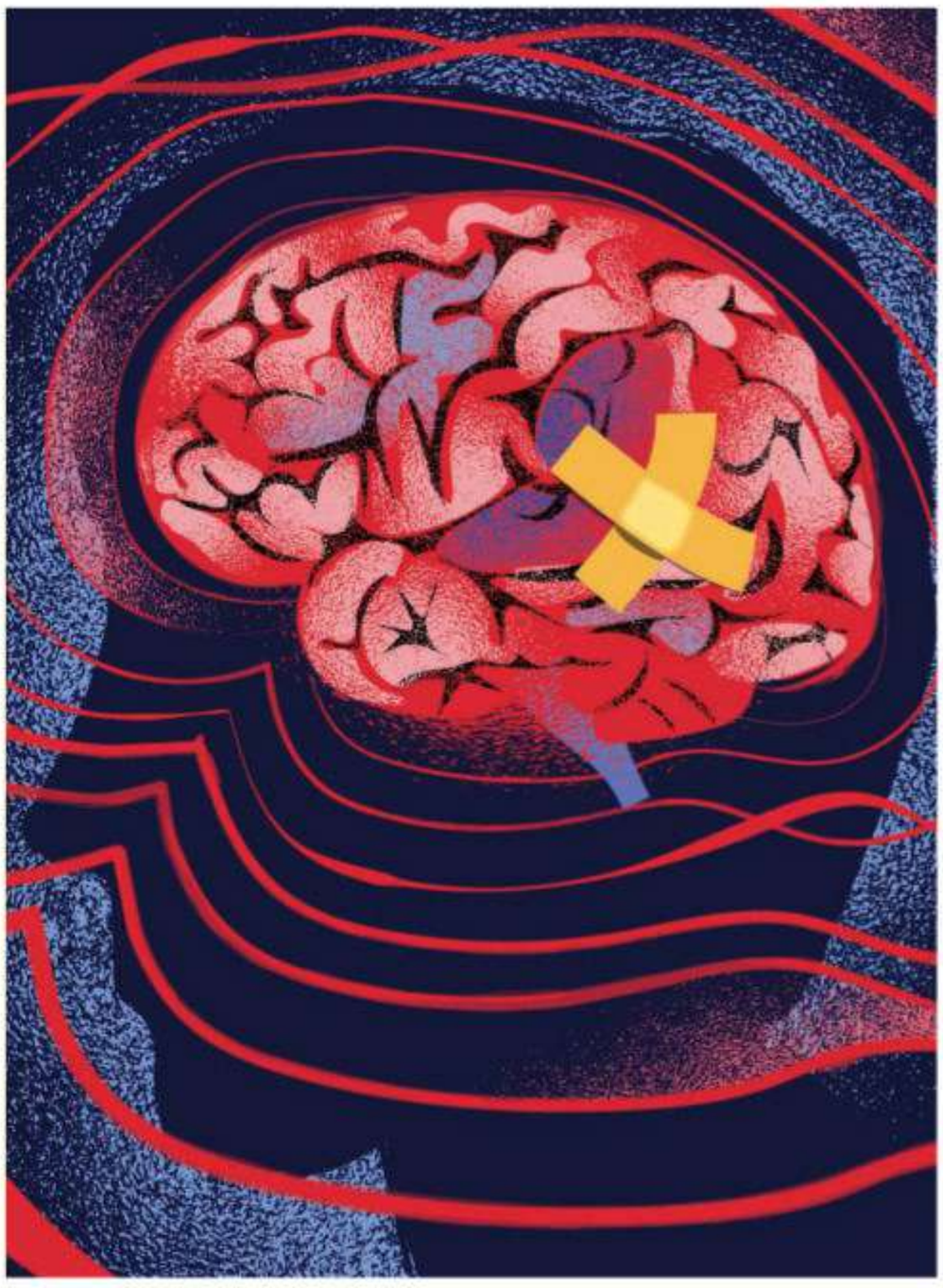

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Take a deep dive into the diverse world of some of the most intelligent invertebrates on planet Earth.

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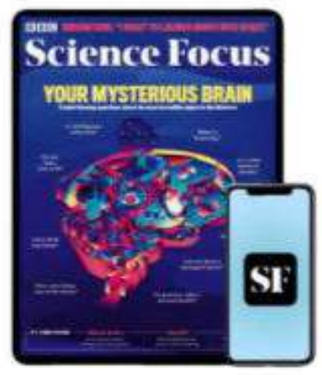

Can't wait until next month to get your fix of science and tech? Our website is packed with news, articles and Q&As to keep your brain satisfied.
sciencefocus.com

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IDEAS WE LIKE...

Finally, after decades of waiting, we are getting a robot butler. Meet Astro, the new bot from Amazon.

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PROF BRIAN COX

"BY ANY DEFINITION THAT I CAN FIND OF THE WORD 'GOD', THE STARS QUALIFY... THEY'RE THE FOUNDATION OF VIRTUALLY ALL LIFE ON EARTH TODAY"

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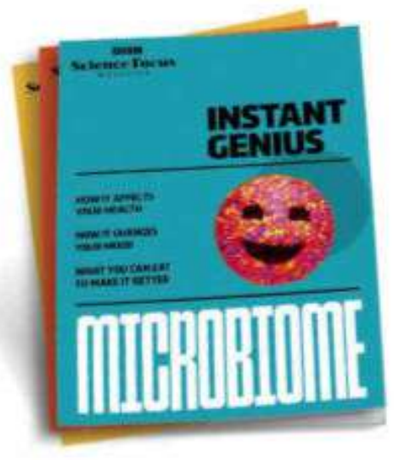

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EYE OPENER

ISS gets a power up

THERMOSPHERE, EARTH

NASA astronaut Shane Kimbrough waves as he and his fellow crew member, ESA astronaut Thomas Pesquet, install new solar arrays on the International Space Station (ISS). The arrays, made up of photovoltaic panels, generate electricity for the ISS. Unlike the fold-out solar arrays that you might have seen on images of the ISS, the new ones, called roll-out solar arrays (ROSAs), unfurl like sails.

For the last 20 years, the scientific investigations conducted on the ISS have been powered by solar arrays that were deployed in 2000 and only designed for 15 years of service. Though showing signs of wear and tear, the arrays are still functioning well, producing 160kW of electricity for the ISS on each orbit. Thanks to the six new ROSAs that Kimbrough and Pesquet installed during three spacewalks in June 2021, the power available to astronauts on the ISS is now 215kW a day. That's enough to power the average home for nearly a month!

NASA

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EYE OPENER

Star of the show

KYUSHU, JAPAN

Here, a male Leach's sea star (*Leiaster leachi*) releases his sperm into the waters around him, where hundreds of other males and females are also 'broadcast spawning'. This huge reproductive event happens once a year and sees hundreds of thousands of eggs and sperm come together in the water.

How these starfish manage such synchronicity is a mystery, says Prof Maurice R Elphick, a biologist at Queen Mary University of London who studies them. "It's likely a combination of water temperature, day length, the lunar cycle and also the presence of eggs, sperm and pheromones from other individuals."

Some of the fertilised eggs will be consumed by predators, but thousands will survive to become larvae and settle on the seabed, says Elphick.

"Then, inside the larva, a tiny, five-sided creature starts to grow before it eventually climbs out and consumes the tissue that's left behind to help it develop into a starfish."

TONY WU/NATUREPL.COM

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CONVERSATION

YOUR OPINIONS ON SCIENCE, TECHNOLOGY AND *BBC SCIENCE FOCUS*

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LETTER OF THE MONTH

Fetch the engines

This summer has seen yet another plethora of forest fires destroying trees, people's homes and doing untold damage to the environment. But the main fire-fighting technique is still to throw water on them, just as we did in the Great Fire of London. Surely science can come up with a better solution?

Dr Barry Culpin

Wildland firefighting nowadays differs very much from the techniques used to fight urban fires. Indeed, many countries have separate teams, training and equipment for wildfires. Water is still used and is what's often seen on TV. But in bigger, more intense fires, there's no way you can extinguish all the flames; you can only stop them from spreading by removing the fuel available and letting the wildfire burn itself out – a technique known as 'indirect attack'. It involves removing the flammable vegetation ahead of the fire by using hand tools or bulldozers, adding retardants or even burning it in a controlled fire. The 'control lines' this creates tend to be made along obstacles in the fire's path, such as a river or road. This stops the fire in its tracks.

Most of the outdoor fires that UK firefighters tend to are small and can be put out with water. But any fire that's big enough to hit the media is usually too big to be completely extinguished with water. You can read more about the wildfire fighting techniques used in the UK at bit.ly/HaltWildfires

Stefan Doerr, professor of wildland fire science at Swansea University

WRITE IN AND WIN!

The writer of next issue's *Letter Of The Month* wins the **shortlist of non-fiction books from the Baillie Gifford Prize,** including *Islands of Abandonment: Life In The Post-Human Landscape; Aftermath: Life In The Fallout Of The Third Reich; Empire Of Pain: The Secret History Of The Sackler Dynasty; Things I Have Withheld; Fall: The Mystery Of Robert Maxwell; Free: Coming of Age At The End Of History* **thebailliegiffordprize.co.uk**

That's the spirit!

I noticed that Aleks Krotoski is wondering what could replace tea as the national beverage (September, p62). Well, we already have a suitable homegrown, sustainable drink produced in Scotland that would resolve all the supply problems, as well as preventing the population from rioting: uisge, or whisky (otherwise known as the water of life). And if HMRC removed the duty from said beverage, all our problems would be solved!

Richard Graham, Aberdeenshire

Suffering in solitude

Loneliness is certainly a problem for many, and one made worse by the COVID lockdowns (October, p30). It can be difficult to make real contacts with others when you're shut away, and some people lack the mobility to do anything about it.

Although Dean Burnett does end the article by saying that loneliness is not inevitable, he could perhaps have said more about the need for people to simply take the initiative. There are plenty of social groups, societies, classes

Loneliness is something most of us are likely to experience at some point in our lives

"THE WAY AI GENERATES MUSIC IN GENERAL IS SIMILAR TO THE WAY YOUR EMAIL TRIES TO PREDICT THE NEXT WORD FOR YOU ... IT JUMPS INTO SUGGESTING WHAT YOU MIGHT WANT TO WRITE NEXT"

PROF AHMED ELGAMMAL, P24

NASA's Perseverance rover has begun collecting samples of the Martian surface to be returned to Earth

and more, often eager for new members. The danger is that loneliness becomes a self-fulfilling prophecy and regarded as something we can do nothing about.
Patrick Forsyth, Essex

While it is true that there will always be a degree of autonomy when it comes to experiencing loneliness, I feel that telling people to "take the initiative" overly simplifies the real causes of it.

Loneliness can stem from many complex factors, like a lack of familiarity with current social norms and methods of interaction, cultural shift, infirmity, and more. There's also the fact that social phobias are the most common types of anxiety disorder. Assuming that loneliness can regularly be fixed purely by personal effort is basically the same as telling someone with clinical depression to 'snap out of it'.
Dr Dean Burnett, *BBC Science Focus* contributor

Mixing with Mars

Dr Albert Haldemann tells us about work being done to return rocks from Mars (August, p66). He says he's not worried about contamination because the Red Planet and Earth have been "sharing spit" for billions of years. But what about the difference in atmospheres, exposures to radiation, not to mention microbes! We know Earth's atmosphere is thicker than Mars's, has more water, and consequently our surface suffers more from erosion. Yet Mars suffers from stellar radiation, solar wind and other phenomena that never seem to affect Earth and humans.
Richard T Stanley

The Mars Sample Return programme involves steps to keep our planet and the Mars samples safe. They will be packaged in several layers, and once returned to Earth, they will be studied using X-rays before the capsules are opened.
Sara Rigby, online staff writer

GETTY IMAGES X2, NASA

THE TEAM

EDITORIAL
Editor Daniel Bennett
Managing editor Alice Lipscombe-Southwell
Commissioning editor Jason Goodyer
Editorial assistant Amy Barrett
Online staff writer Sara Rigby

ART
Art editor Joe Eden
Picture editor James Cutmore

CONTRIBUTORS
Claire Asher, Scott Balmer, Robert Banino, Hayley Bennett, Peter J Bentley, Steve Boswell, Daniel Bright, Steve Brusatte, Dean Burnett, Stuart Clark, Lisa Feldman Barrett, Alex Franklin Cheung, Alastair Gunn, Christian Jarrett, Christina Kalli, Stephen Kelly, Aleks Krotoski, Pete Lawrence, Nish Manek, Michael Mosley, Cody Muir, Katy Munro, Adrian M Owen, Helen Pilcher, Helen Scales, Bart Van Der Sloot, Colin Stuart, Luis Villazon, Joe Waldron, Kimberley Wilson.

ADVERTISING & MARKETING
Group advertising manager Gino De Antonis
Newstrade manager Helen Seymour
Subscriptions director Jacky Perales-Morris
Direct marketing manager Kellie Lane

MOBILE
Head of apps and digital edition marketing Mark Summerton

INSERTS
Laurence Robertson 00353 876 902208

LICENSING & SYNDICATION
Director of licensing and syndication Tim Hudson
International partners manager Anna Brown

PRODUCTION
Production director Sarah Powell
Production coordinator Georgia Tolley
Ad services manager Paul Thornton
Ad designer Julia Young

PUBLISHING
Publisher Andrew Davies
Group managing director Andy Marshall
CEO Tom Bureau

BBC STUDIOS, UK PUBLISHING
Chair, editorial review boards Nicholas Brett
Managing director, consumer products and licensing Stephen Davies
Director, magazines and consumer products Mandy Thwaites
Compliance manager Cameron McEwan
UK publishing coordinator Eva Abramik
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EDITORIAL COMPLAINTS
editorialcomplaints@immediate.co.uk

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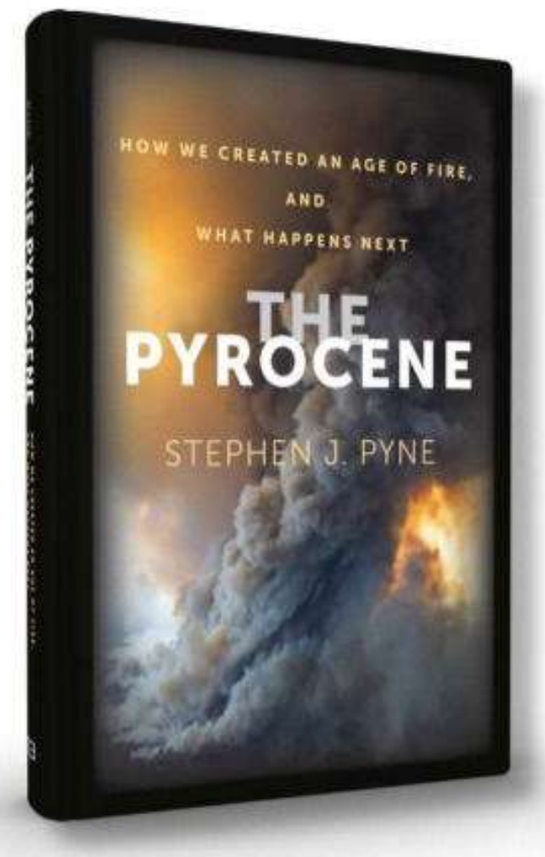
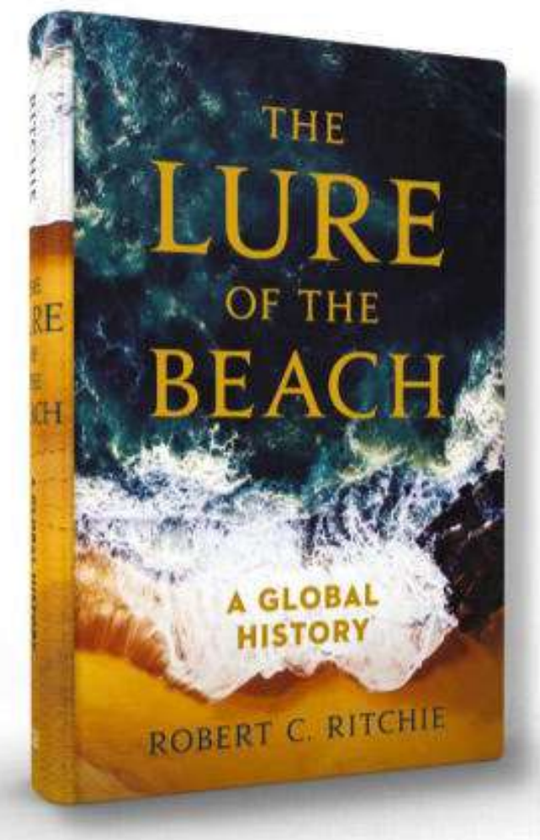
ENVISIONING THE WORLD'S FUTURES

AND VIEWING ITS PAST



"How humanity has entered a new age of fire, one that redefines the human-altered era of the Anthropocene."
—Nature



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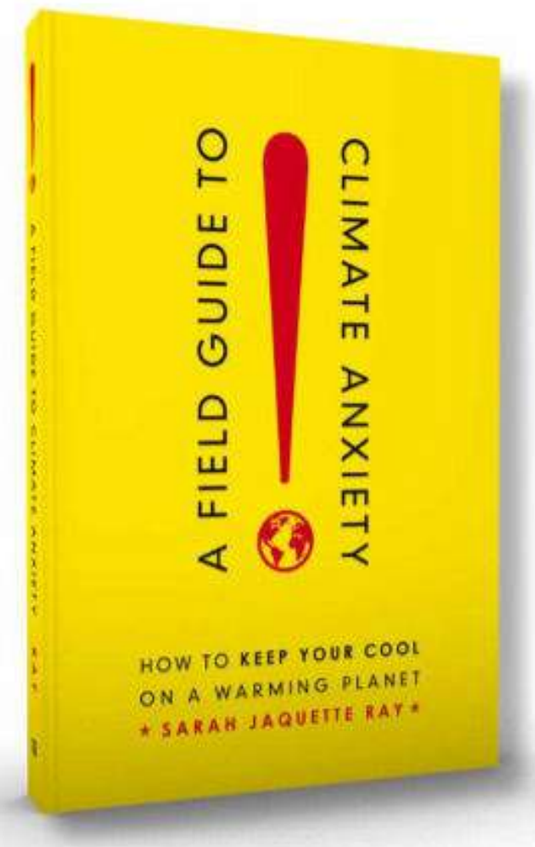
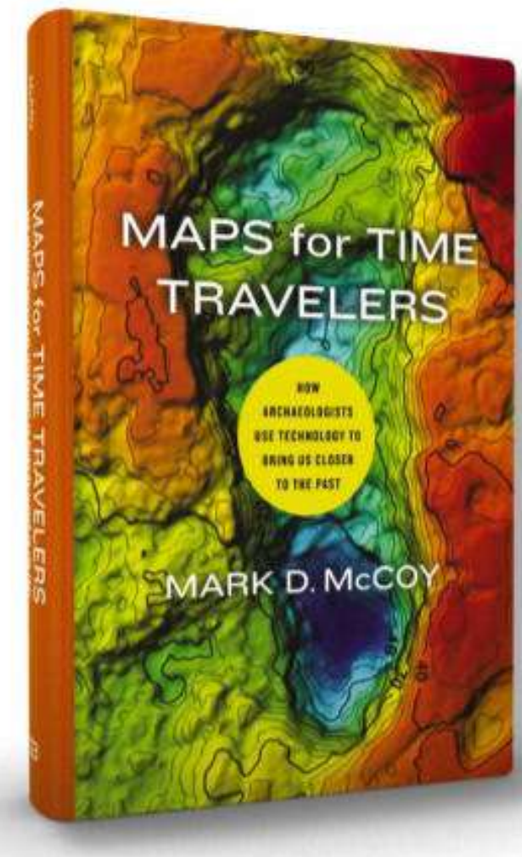
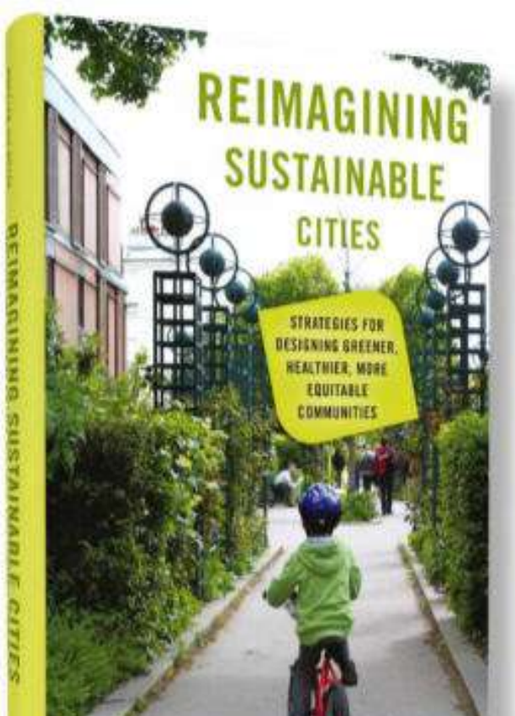


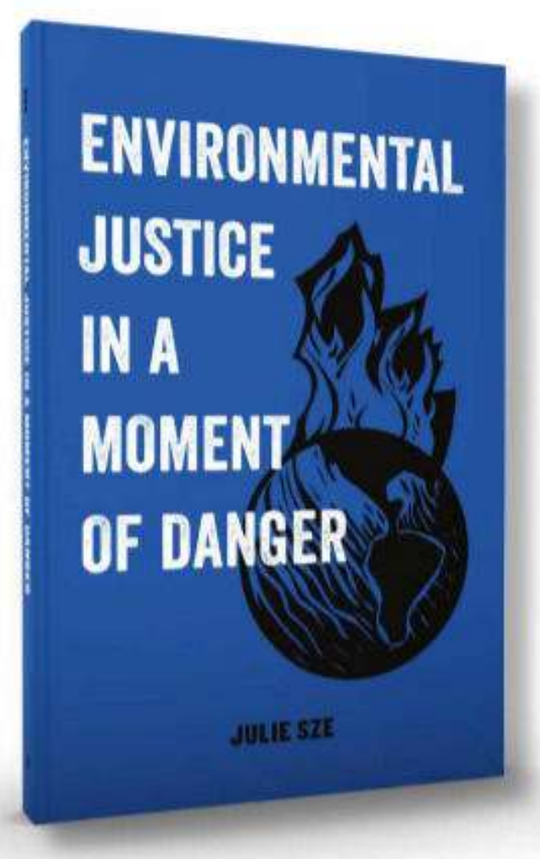
"Strategies that can help people of any age to play the long game of fighting for climate justice."
—Australian Journal of Environmental Education



"[An] impassioned study written to change popular perceptions of archaeology."
—Nature


REIMAGINING SUSTAINABLE CITIES
STRATEGIES FOR DESIGNING GREENER, HEALTHIER, MORE EQUITABLE COMMUNITIES
STEPHEN M. WHEELER and CHRISTINA D. ROSAN

"A refreshingly optimistic and well-argued big picture explanation of sustainable urban development and climate change clearly written for a general audience."
—Richard LeGates, Professor Emeritus, San Francisco State University



"A concise and powerful description of environmental injustices."
—Claudia Rapp, University of Vienna and Austrian Academy of Sciences

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WORLD'S FIRST MALARIA VACCINE

The World Health Organization's director-general hails 'historic moment' as mass immunisation of African children begins

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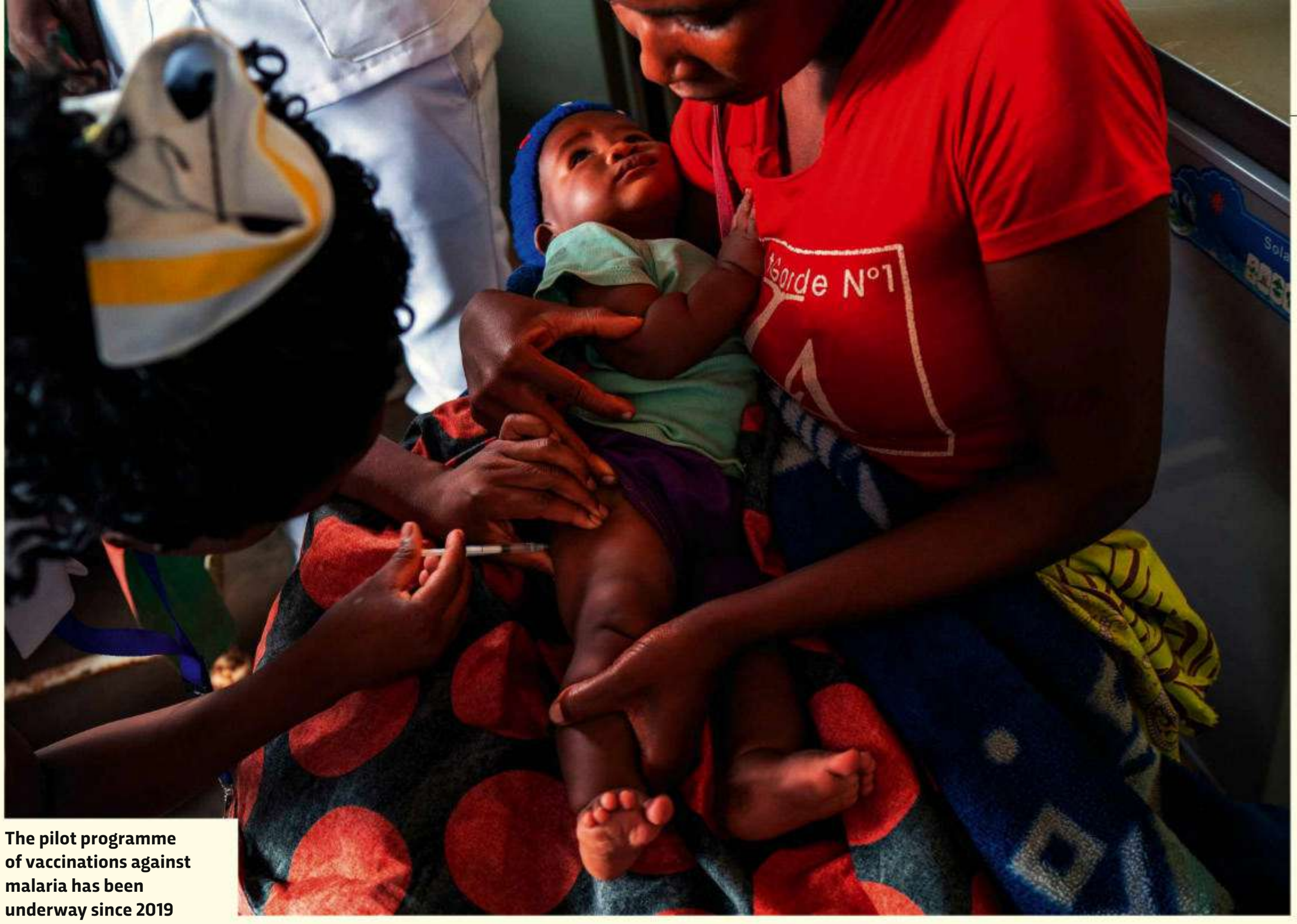


The pilot programme of vaccinations against malaria has been underway since 2019

Malaria is the largest cause of childhood illness and death in sub-Saharan Africa, killing more than 260,000 under-fives every year. For context, that means one child dies of malaria every two minutes.

Now, following a successful pilot scheme that involved giving at least one dose of the RTS,S/AS01 malaria vaccine to more than 800,000 children across Ghana, Kenya and Malawi, the World Health Organization (WHO) is recommending a widespread immunisation programme for children aged five months or older living in sub-Saharan Africa. This marks the first time that a vaccine for malaria has been recommended for use across large swathes of the continent.

"This is a historic moment. The long-awaited malaria vaccine for children is a breakthrough for science, child health and malaria control," said WHO director-general Dr Tedros Adhanom Ghebreyesus. "Using this vaccine on top of existing tools to prevent malaria could save tens of thousands of young lives each year."

Malaria is caused by the *Plasmodium* parasite, which is spread by female *Anopheles* mosquitoes. Once the parasite enters the host's bloodstream it travels to the liver, where it develops for a short period before re-entering the bloodstream and attacking the host's red blood cells. In a non-immune individual, symptoms usually appear 10 to 15 days after the bite and include fever, headache, chills and diarrhoea. If not treated within 24 hours, the disease can progress to become a severe illness and often leads to death.

Developing an effective vaccine has proved to be a serious challenge as the parasite is far more complex than a virus or bacteria.

The RTS,S vaccine works by introducing the immune system to a fragment of a protein that is present on the surface of the *Plasmodium* parasite. The protein triggers the production of antibodies and prepares the immune system to attack the parasite the next time it enters the body. It is administered to children via a schedule of four doses and, to date, more than 2.3 million have been given, with no significant side effects.

"The long-awaited malaria vaccine for children is a breakthrough"

WHO has reported a 30 per cent reduction in the cases of deadly malaria since the pilot scheme began in 2019, even in areas where insecticide-treated nets are widely used and people have good access to diagnosis and treatment.

Discussions about funding a broader rollout of the vaccine will now take place among the global health community, with individual countries making the decision on whether to adopt the vaccine as part of their national malaria control strategies.

"For centuries, malaria has stalked sub-Saharan Africa, causing immense personal suffering," said Dr Matshidiso Moeti, WHO regional director for Africa. "We have long hoped for an effective malaria vaccine and now, for the first time ever, we have such a vaccine recommended for widespread use. Today's recommendation offers a glimmer of hope for the continent, which shoulders the heaviest burden of the disease and we expect many more African children to be protected from malaria and grow into healthy adults."

ARCHAEOLOGY

Humans used 'modern' fishing tools more than 12,000 years ago

The people who used these weights, hooks and lures "knew all there was to know about fish"

Ancient humans in the Middle East used sophisticated fishing tools 12,000 to 15,000 years ago, a study has found.

Ancient fishing is hard to study, since many of the materials used, such as plant fibres and wood, are perishable. But one of the largest collections of early fishing technology provided a team of researchers with an insight into the techniques used.

The team, led by Dr Antonella Pedergnana of the Römisch-Germanisches Zentralmuseum Archaeological research institute in Germany, studied 19 bone fish hooks and six grooved stones from the Jordan River Dureijat (JRD), an Epipalaeolithic site in Hula Valley, northern Israel.

"The hooks are amazingly similar to modern hooks – in size, in features like barbs, and in dexterity of making," said Prof Gonen Sharon of Tel Hai College, Israel. "Moreover, the hooks present features that are rarely found in modern-day hooks – for example, an outer lower barb aiming to function as a 'point of no return' to prevent the fish from escaping the hook." The researchers believe that the grooved stones were used as weights.

These sophisticated tools arose during a seismic shift in human history: the change from nomadic to agricultural lifestyles. The people who used these fishing tools were an in-between stage. They were hunter-gatherers, but they lived in one place, in stone houses. As a result, they relied heavily on fish. While other resources could be exhausted, fish stocks were replenished more easily and available year-round.

There was a huge variety in the hooks, showing that the people using them understood that different tools were needed for different fish. "Looking at the hooks, we see that no two are similar. Each hook is different in size, features and style," said Sharon. "This variability can be explained by the excellent knowledge these people had regarding fish behaviour. They knew exactly what size of hook was good for what size and type of fish, and what features were needed to get the best results for each fish type. We also know, from the fish bones found at the site, that the size of fish caught ranges between very small fish to giant carp over two metres in length."

Though the tools were similar to modern hooks in many ways, there were some differences, too. "The JRD fishers didn't drill holes in the hooks, possibly because the bones were not strong enough, but instead used sophisticated and diverse methods of attaching the line to the hook and weights, like grooves, bulges and knots, even glue."

Some of the grooves and plant fibre residues on the bends of the hooks suggest that the fishers were using artificial lures.

"The use of fly fishing indicates a full and deep knowledge of fish behaviour," said Sharon. "You need to know that some fish hunt by attacking insects near the surface and will attack an artificial bite that pretends to be a fly. So, by 13,000 years ago they knew all there was to know about fish of the Hula Lake."

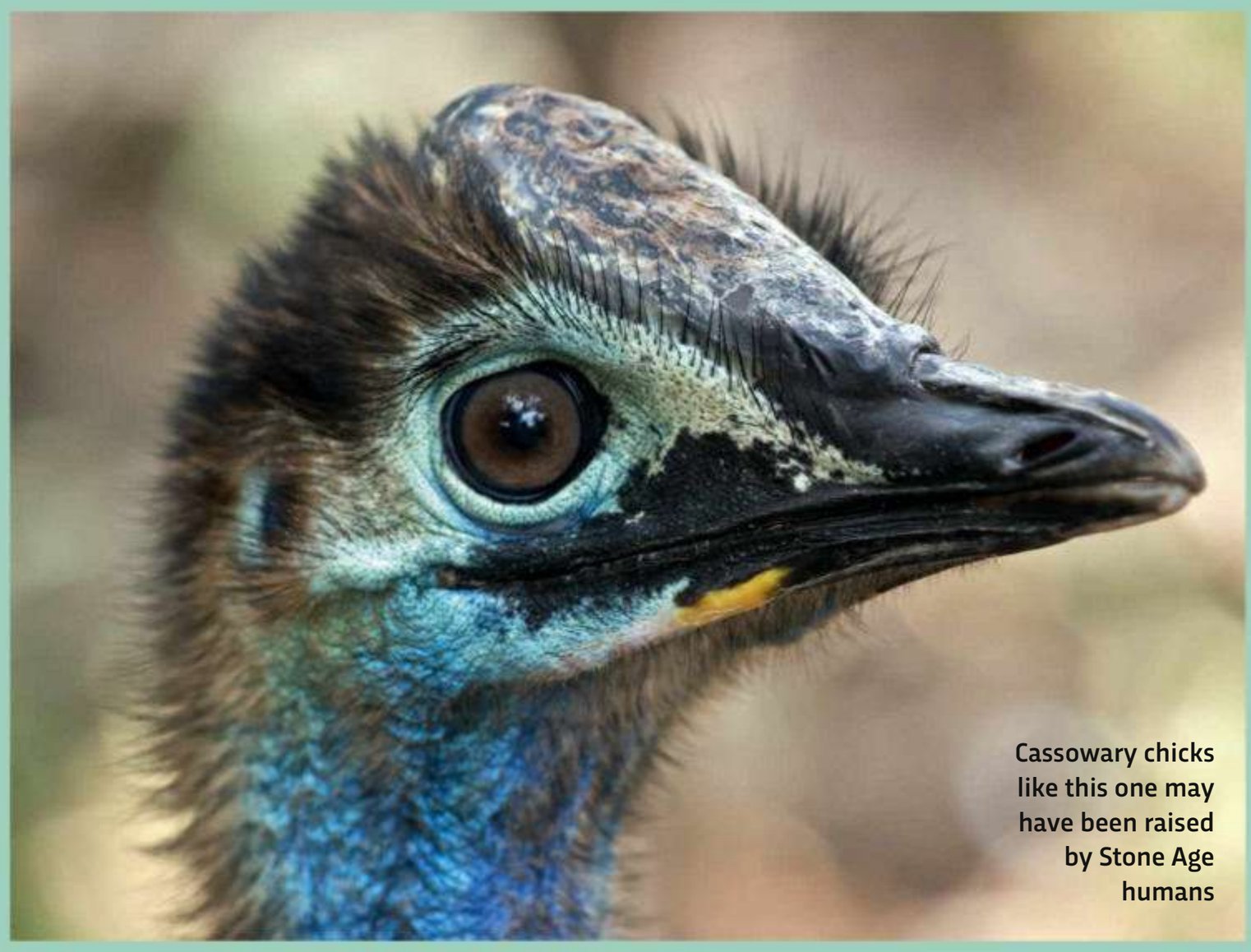
"This variability can be explained by the excellent knowledge these people had regarding fish behaviour"

SHUTTERSTOCK, EMANUELA CRISTIANI

The hooks and weighted lines indicate the fishers were highly skilled

HUMANS

Stone Age humans hatched and raised cassowary chicks in New Guinea



Cassowary chicks like this one may have been raised by Stone Age humans

Thousands of years before the domestication of the chicken, humans were collecting cassowary eggs before they hatched

Up to 18,000 years ago, humans in New Guinea were hatching cassowary chicks and may have raised them to adulthood, a new study has found. This suggests that chickens may not in fact have been the first domesticated birds.

Cassowaries are big, flightless birds native to Australia, the Aru Islands in Indonesia, and New Guinea.

"This is not some small fowl, it is a huge, ornery, flightless bird that can eviscerate you," said co-author Kristina Douglass, assistant professor of anthropology and African studies, Penn State.

The chicks are still traded as a commodity in New Guinea today, and will easily imprint on humans. If the first thing a chick sees is a human, it will follow them around as though they were its mother.

The researchers studied eggshells from between 18,000 and 6,000 years ago to determine how old the chicks inside were when they were cracked. Developing chicks get calcium from their eggshells, with pits appearing on the inside of the shell during later stages. By studying the shells, the scientists established that the large majority of the eggs were harvested during the late stages of development.

While it's possible they were eating baluts – an Asian street food that involves boiling a near-developed chick in its shell – many of the samples didn't show any evidence of burn marks, suggesting that the eggs were hatched. This is particularly remarkable, given that the domestication of chickens happened thousands of years afterwards.

"The implications of this are enormous!" said Dr Hanneke Meijer, a palaeontologist who was not involved with the research. "It is generally considered that chickens were the first domesticated birds – although the date and place of domestication, whether it was one event or several, remains highly contested – but this research shows that this might not be the case."

The team can't say for sure what the birds were used for. The archaeologists who originally studied the site found no evidence that the cassowaries were kept in a pen. However, the only cassowary bones found at the site were from the leg and thigh, suggesting they had been hunted and only the meatiest parts were taken home.

"There is evidence that cassowaries were transposed to other nearby islands and this is easiest to do with chicks because adult cassowaries can be vicious. So they were likely seen as a source of food," said Meijer. "But human-bird relationships are often multifaceted and the birds might have been kept for their feathers, or even played a role in symbolism and rituals, as is the case today. Finally, I can also imagine that if we were to go back in time to New Guinea in the early Holocene, we might have seen children chasing around and playing with little cassowary chicks."

"It is generally considered that chickens were the first domesticated birds, but this research shows that this might not be the case"

GETTY IMAGES X4, ALAMY, SHUTTERSTOCK, TANIS LAB/UD BIO-IMAGING CENTRE/JEFFREY C CHASE

The world's five biggest birds

5. EMU
Maximum weight: 55kg
Distribution: Australia
Of the four surviving members of the family Casuariidae, three are cassowaries, and the fourth is the emu. Adult emus can stand at 190cm tall. They weigh on average between 30 and 45kg, but the largest reach 55kg.

4. NORTHERN CASSOWARY
Maximum weight: 58kg
Distribution: New Guinea
Like other species of cassowary, *Casuarius unappendiculatus* is a flightless bird. After being laid by a female, the eggs of this species are incubated by a male who raises them for nine months. They can reach 180cm in height.

3. SOUTHERN CASSOWARY
Maximum weight: 76kg
Distribution: New Guinea and Queensland, Australia
The southern cassowary (*Casuarius casuarius*) is slightly larger than its cousin, the northern cassowary. They live in rainforests, swamp forests and savannah woodland, and can grow up to 180cm in height.

2. SOMALI OSTRICH
Maximum weight: 105kg
Distribution: Horn of Africa
Once believed to be a subspecies of the common ostrich, *Struthio molybdophanes* was confirmed as a separate species in 2014.

1. COMMON OSTRICH
Maximum weight: 156kg
Distribution: Savannahs of Africa
Males of the species *Struthio camelus* can reach a whopping 2.75m tall. These flightless birds are incredible runners, and can achieve speeds of 70km/h (43mph) in a sprint.

HEALTH

Vitamin B12 could protect the brain against Alzheimer's, wiggling worm study suggests

Healthy levels of vitamin B12 may help to prevent damage from the buildup of toxic proteins in the brain

There are currently more than 850,000 people in the UK living with dementia, of these between 50 to 75 per cent have Alzheimer's. If current trends continue, the Alzheimer's Society estimates that there could be 1,590,000 people with dementia by 2040.

There are as yet no effective treatments for Alzheimer's, but a team from the University of Delaware has found new clues that diet could have an impact on the progression of the disease.

In this false-colour image, the fluorescent colour indicates the worm is deficient in vitamin B12

In the brains of humans with Alzheimer's, a buildup of the protein amyloid beta causes toxic effects in cells, resulting in reduced energy, fragmentation of the mitochondria – the cells' power plants – and oxidative stress.

In *C. elegans*, tiny soil-dwelling worms often used to study biology and disease, an accretion of amyloid beta causes paralysis within 36 hours of them reaching adulthood. This was easily observed, as the worms stopped wriggling.

The team found that when fed with *E. coli* bacteria containing higher levels of vitamin B12, *C. elegans* were protected from this paralysing effect.

"The read-out is black or white – the worms are either moving or they are not," said lead researcher Prof Jessica Tanis. "When we gave vitamin B12 to the worms that were vitamin B12 deficient, paralysis occurred much more slowly, which immediately told us that B12 was beneficial. The worms with B12 also had higher energy levels and lower oxidative stress in their cells."

After further study, the team found that adding the vitamin to the worms' diet only helped if they were deficient in B12 to begin with – supplementing healthy animals with B12 had no effect.

"Right now, there is no effective treatment for Alzheimer's disease," Tanis said. "There are certain factors that you cannot change – you cannot change the fact that you age, and you cannot change a genetic predisposition to Alzheimer's disease.

"But one thing you can control is what you eat. If people could change their diet to affect the onset of disease, that would be fantastic. That's something my lab is excited to continue to explore."

HEALTH

Psychedelic drug found in magic mushrooms enhances our emotional response to music

The finding could be important for the therapeutical use of psychedelics

Psilocybin, the psychedelic drug found in magic mushrooms, can affect the way we emotionally respond to music, a study by Danish scientists has found.

The drug has previously been used with some success in clinical trials designed to treat depression. These trials typically involve the use of music to support the psychedelic experience.

Previous studies have found that LSD, another psychedelic drug, can enhance the emotional responses triggered by music, so the team wanted to find out if psilocybin had a similar effect.

The team had 20 healthy participants listen to a short programme of music comprising Elgar's *Enigma Variations VIII* and *IX*, and Mozart's *Laudate Dominum*, before and after taking a controlled dose of psilocybin. After each playthrough, the participants rated their emotional responses according to the Geneva Emotional Music Scale. The psilocybin increased their emotional response to the music by an average of 60 per cent.

"This shows that the combination of psilocybin and music has a strong emotional effect, and we believe that this will be important for the therapeutic application of psychedelics if they are approved for clinical use," said lead researcher Dr Dea Siggaard Stenbæk, an associate professor at the University of Copenhagen.

"Psilocybin is under development as a drug to treat depression, and this work implies that music needs to be considered as a therapeutic part of the treatment. Interestingly, some of the music we used, Elgar's famous *IX Variation*, describes his close friend Augustus Jaeger. Jaeger encouraged Elgar to write the variations as a way out of depression, so we're pleased to see it used again to help understand more about mental health."

The researchers now plan to investigate the effect of music on the brain while under the influence of psilocybin using an MRI scanner.

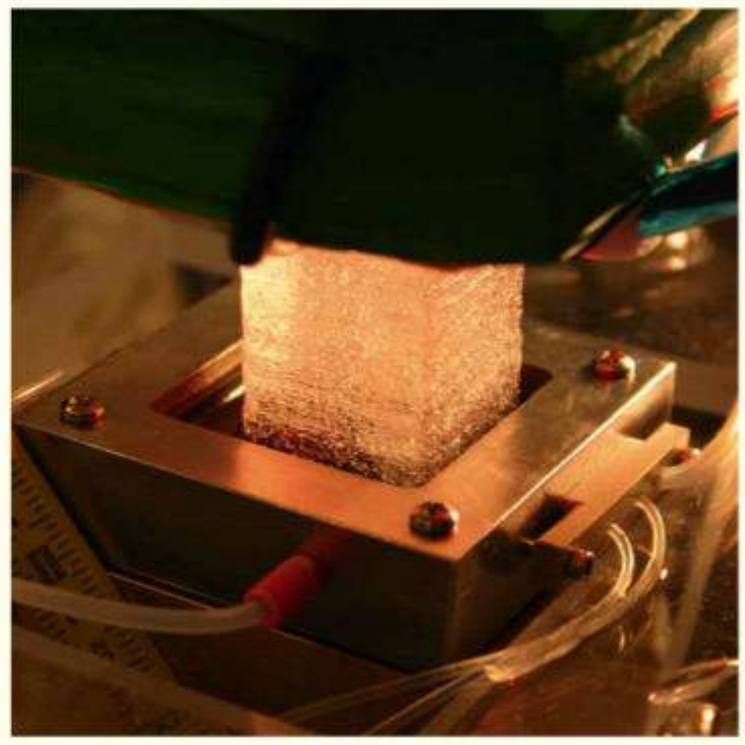
"This is further evidence of the potential of using music to facilitate treatment efficacy with psychedelics," said Prof David J Nutt, a psychedelics researcher at Imperial College, London, who was not involved in the research. "What we need to do now is optimise this approach, probably through individualising and personalising music tracks in therapy."

"This shows that the combination of psilocybin and music has a strong emotional effect"

GETTY IMAGES, JACK TRIEST, JOE MCCONNELL/DRI

WARNING

Psilocybin is a Class A drug according to UK law. Anyone caught in possession of such substances will face up to seven years in prison, an unlimited fine, or both. More information and support for those affected by substance abuse problems can be found at **bit.ly/drug_support**



ENVIRONMENT

Māori land-burning practices triggered a rise in carbon emissions

The arrival of the Māori people to New Zealand in the 14th Century led to a major increase in black carbon, hundreds of years before the Industrial Revolution

While studying ice core samples taken from James Ross Island in Antarctica, scientists from the British Antarctic Survey noticed something unexpected – the levels of black carbon, or soot, began to increase dramatically about 700 years ago.

Black carbon is a part of the fine particulate air pollution that contributes to climate change. It is one of many particles that are emitted by the burning of diesel or coal, or by forest fires.

The team analysed the ice core taken from James Ross Island and compared it to others taken from across continental Antarctica. While the ice core from James Ross Island showed a notable increase in black carbon that started in the year 1300 and tripled over the next 700 years, black carbon levels across continental Antarctica stayed relatively stable.

To pinpoint the source of the black carbon, they used atmospheric model simulations around the southern hemisphere. They found that the most likely candidates for the origin of the black carbon were Patagonia, Tasmania, and New Zealand.

To narrow this down further, they then checked the charcoal records of each of the three regions and found that there was a major increase in fire activity in New Zealand around the year 1300 – the estimated arrival date of the Māori people.

"The idea that humans at this time in history caused such a significant change in atmospheric black carbon through their land-clearing activities is quite surprising," said Dr Joe McConnell, research professor of hydrology at Desert Research Institute who designed and led the study.

"We used to think that if you went back a few hundred years you'd be looking at a pristine, pre-industrial world, but it's clear from this study that humans have been impacting the environment over the Southern Ocean and the Antarctica Peninsula for at least the last 700 years."

The finding was unexpected due to New Zealand's relatively small land area and the 7,000km distance that the smoke would have had to travel to reach James Ross Island.

"Compared to natural burning in places like the Amazon, or southern Africa, or Australia, you wouldn't expect Māori burning in New Zealand to have a big impact, but it does over the Southern Ocean and the Antarctic Peninsula," explained Dr Nathan Chellman, postdoctoral fellow at Desert Research Institute.

ABOVE LEFT Dr Robert Mulvaney with the James Ross Island ice core

ABOVE Analysing the chemistry inside the ice

PALAEONTOLOGY

Volcanoes may have given dinosaur evolution a helping hand

The rise of the dinosaurs seems to be connected to a period of violent volcanic activity more than 230 million years ago

Triceratops, Stegosaurus, Tyrannosaurus rex, Diplodocus… it turns out that the hundreds of species of dinosaurs we know today may have arisen because of volcanoes, according to an international team of researchers.

During the late Triassic Period, there was a stretch of time known as the Carnian Pluvial Episode (CPE), which ran from 234 to 232 million years ago.

Before the CPE, the supercontinent of Pangaea was dry and arid, but then the CPE came along with its 'mega monsoon climate', leading to an increase in global temperature and humidity. This transformation of conditions had a major impact on plant and animal life.

"Within the space of two million years, the world's animal and plant life underwent major changes, including selective extinctions in the marine realm and diversification of plant and animal groups on land," said co-author Prof Jason Hilton. "These events coincide with a remarkable interval of intense rainfall known as the Carnian Pluvial Episode."

After analysing sediment and fossil records from northern China, the researchers propose that volcanic activity could have led to the significant climate change seen during the CPE.

They found that there were four distinct events during the CPE, with each one being driven by pulses of powerful volcanic activity. These eruptions released enormous amounts of carbon dioxide into the atmosphere, which triggered a rise in global temperature and humidity.

The likely source of these powerful eruptions was the Wrangellia large igneous province, the remnants of which are preserved in North America today.

"This relatively long period of volcanic activity and environmental change would have had considerable consequences for animals on land," said Dr Emma Dunne, a palaeobiologist at the University of Birmingham, who was not involved in the study.

"At this time, the dinosaurs had just begun to diversify, and it's likely that without this event, they would never have reached their ecological dominance we see over the next 150 million years."

As well as dinosaurs, the CPE was also important for the rise of modern conifers, and had a huge impact on the evolution of ferns, crocodiles, turtles, insects and early mammals.

"Around 232 million years ago, dinosaurs emerged from their small, humble ancestors and began to diversify," said Dr Steve Brusatte, a palaeontologist at the University of Edinburgh, who was not involved in the research. "Although the evidence is a little circumstantial at this point, there's reason to believe this change from drier to more humid conditions helped trigger the rise of dinosaurs."

He added: "This new study takes the story a step further, and implicates big volcanic eruptions as the source of the climate change. Putting the pieces together, it looks like there was a chain reaction in the Triassic: big volcanoes erupt, they change the climate from dry to humid, and that helps catalyse the spread of dinosaurs. This shows how big changes in climate can have big implications for evolution. It's not just that climate changes can cause extinctions, but they can also help certain groups prosper and spread."

Ecological changes 230 million years ago paved the way for dinosaurs to become dominant

Deformed wing virus causes wings to become stunted or shrivelled, like this honeybee's

PIXABAY, MD KERN/PALO ALTO JR MUSEUM/NATUREPL.COM

ZOOLOGY

A 'supplement' for bees could save colonies from a deadly virus

Scientists have found a plant-based compound that could save honeybee colonies from a virus that deforms wings, causes paralysis and wipes out hives

We all know that we need to save the bees. Their numbers are in decline, thanks to everything from climate change to pesticides.

But another big threat to the insects is a parasite called the *Varroa* mite. Not only do these tiny mites feed on bee larvae inside the hive, they also carry a number of viruses that can wreak havoc on a bee colony. Once infected with the virus, bees can develop wing deformities and suffer from paralysis and a loss of the coordination needed to keep the hive going.

One particularly damaging virus carried by the *Varroa* mite is the 'deformed wing virus' that causes bees' wings to crumple or be stunted in growth. The virus can also affect their memories, which often leads to worker bees – the ones responsible for finding food – leaving the hive and not being able to find their way back. The resulting lack of food and workers can lead to the colony collapsing.

However, new research carried out by researchers at National Taiwan University has revealed that a plant-based compound, sodium butyrate (NaB), could be given to bees on a regular basis to strengthen the hive against an attack by the deformed wing virus.

"This compound could be like taking a vitamin for humans," first author Cheng-Kang Tang, a postdoctoral entomologist, said. "It could make the honeybees stronger if they were given it regularly."

NaB is a chemical compound made up of sodium, carbon, hydrogen and oxygen. It is found naturally in certain foods, and is also produced in the human gut when we digest fibre.

"This compound could make the bees stronger if they were given it regularly"

When eaten by bees, NaB increased the activity of the genes targeted by the deformed wing virus – particularly in the areas of the brain that control learning and memory.

By treating the bees before they caught the deformed wing virus, the researchers were able to save more than 90 per cent of a colony over a five-day period. This compares to a survival rate of just 10 per cent in untreated bees.

"We also found previously that NaB can upregulate some immune response genes in bees," said lead author Prof Yueh-Lung Wu. "This can help suppress viral replication and improve bees' chances at survival.

"Sodium butyrate is really cheap. So, if we can prove its benefits, it would be an easy and affordable approach for beekeepers to keep their bees alive.

"Honeybees are important pollinators of myriad fruits and vegetables with economic importance worldwide and therefore are crucial for maintaining the balance of the ecosystem."

The researchers also noticed the colony that had been receiving the NaB treatment made more honey compared to the infected hive.

"So, we could follow up with a new project looking at the effects [of NaB] on agriculture and honey production," said Tang.

How to...

...help a bee in need

If you spot a bee that appears to be struggling, gently put them onto a bee-friendly flower to allow them time to recuperate. If there are no flowers around, you can put a 50/50 mix of sugar and water into a teaspoon or upturned bottle cap and place it in front of the bee to provide them with a carbohydrate boost and get them flying again.

PHOTOGRAPHY

Image of spawning groupers nets Wildlife Photographer of the Year prize

Now in its 57th year, the Wildlife Photographer of the Year competition continues to give us a fascinating insight into the lives of animals around the world.You can see all the images from the competition at the Natural History Museum, London, until 5 June 2022.

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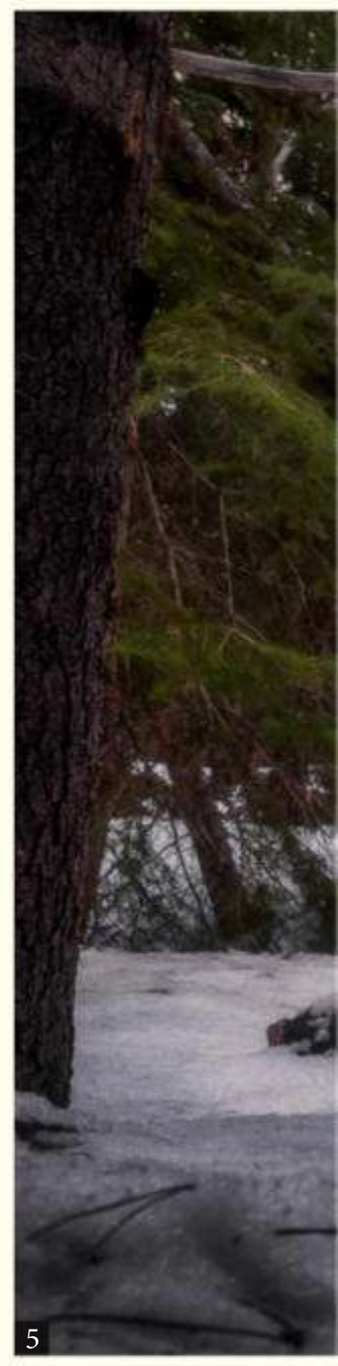


5

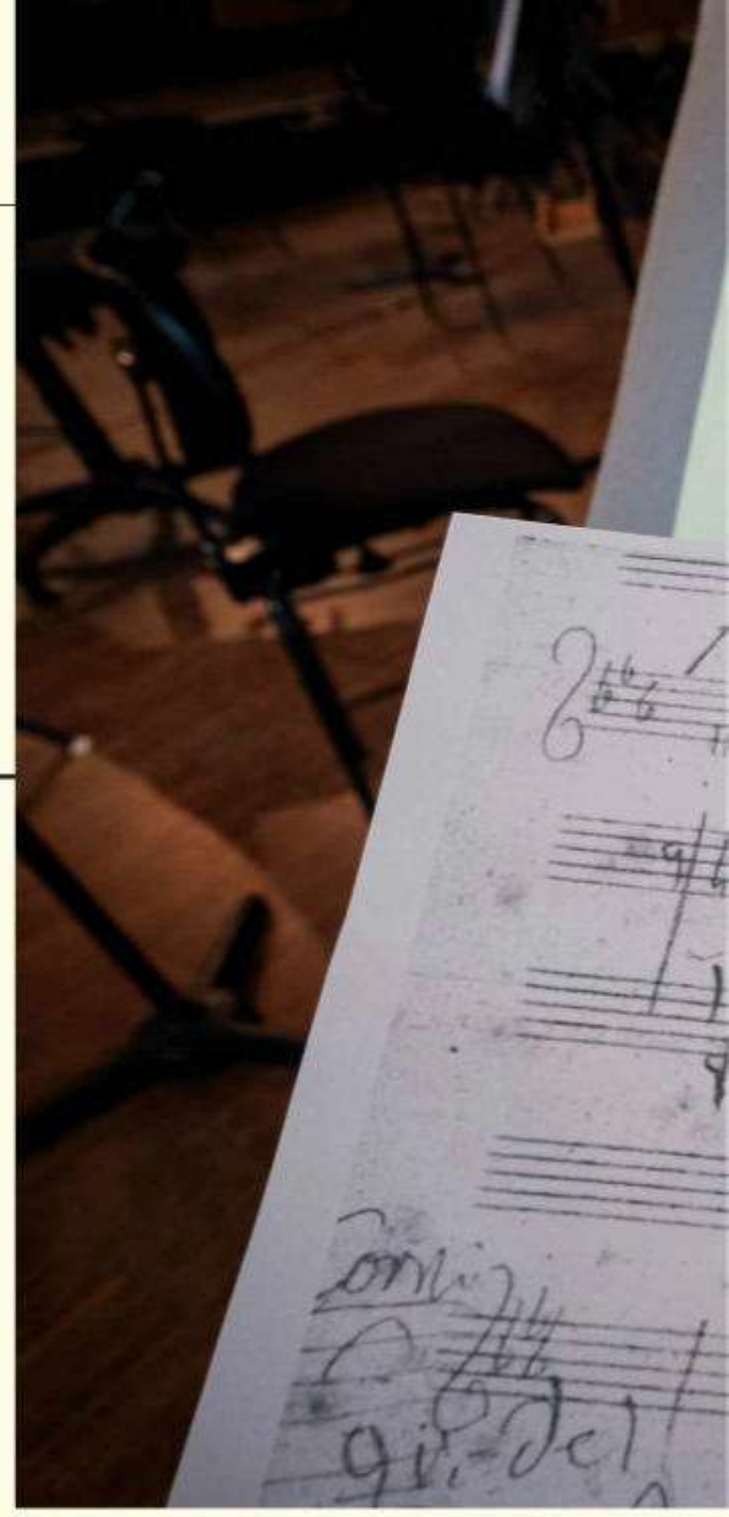
1. Grand Title Winner: *Creation*
by Laurent Ballesta
Every July, during the full Moon, camouflage groupers gather for one hour to spawn in the waters of Fakarava, an atoll in French Polynesia. Laurent Ballesta had been trying to capture an image like this for five years.

2. Winner, Urban Wildlife: *The Spider*
by Gil Wizen
Gil Wizen found this Brazilian wandering spider and its brood under his bed. The hand-sized spiders are highly venomous and their bite can leave men with a painful, long-lasting erection.

3. Winner, Behaviour (Mammals): *Head To Head*
by Stefano Unterthiner
Two reindeer lock antlers during the rutting season in Svalbard, Norway. Every year the males battle for mating rights. In this case, the bull on the left emerged as the victor.

4. Winner, Photojournalism: *Elephant In The Room*
by Adam Oswell
This shot was taken to highlight concerns about the welfare of captive elephants who are made to perform in an unnatural manner at tourist attractions in Thailand.

5. Winner, Animals In Their Environment: *Grizzly Leftovers*
by Zack Clothier
This grizzly bear looks decidedly sheepish as it closes in on the remains of the elk Zack Clothier decided to use as the focus of his camera trap.

PROF AHMED ELGAMMAL
Computer scientist

Interview

Beethoven's unfinished 10th Symphony completed by an AI

Computer scientists teamed up with historians, musicologists and composers to teach an artificial intelligence how to compose like Beethoven

When he died in 1827 at the age of 56, Ludwig van Beethoven left his 10th Symphony unfinished. Only a few handwritten notes briefly detailing his plans for the piece have survived, with most just being incomplete ideas or fragments of themes or melodies.

Now, a multidisciplinary team of computer scientists at Rutgers University-based start-up Playform AI have trained an AI to mimic the great composer's style and used it to write a complete symphony based on these initial sketches.

We spoke to the lead researcher on the project, Prof Ahmed Elgammal, to find out more.

HOW MUCH OF BEETHOVEN'S MANUSCRIPT WAS AVAILABLE FOR YOU TO START FROM?

Beethoven left sketches in different forms, mainly musical sketches, but also some written notes with some ideas in as well. Previously, in 1988 [English musicologist] Barry Cooper used the majority of these sketches, about 250 bars of music, that were meant for a first movement [in his attempt to complete the symphony]. But what was left behind is really very little. So basically, like three bars of music here and four bars of music there and some rough sketches, which sound like basically the starting points of the main themes in the movements that he [Beethoven] wanted to write.

When you look at Beethoven and other classical composers, that's usually the case. They will work with a main theme and then develop it into a sequence of a couple of minutes and then another theme comes. That's the traditional way of composing, and that's exactly what the AI needed to learn: how Beethoven and other classical composers start with a theme and develop it. Like in the Fifth Symphony – 'da da da dah'. And then take that and evolve a whole movement around it.

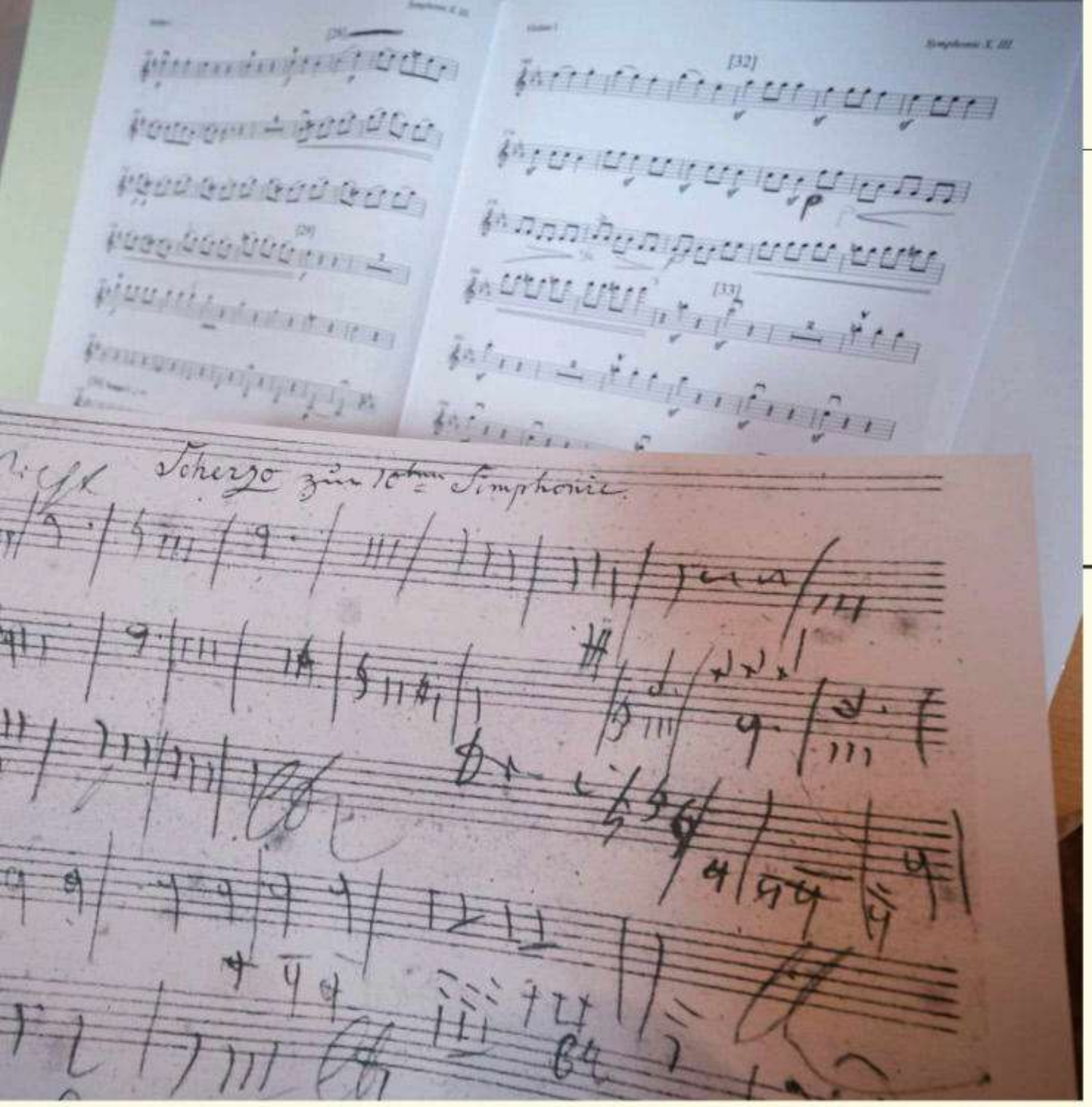
HOW DO YOU TRAIN THE AI TO DEVELOP INTERESTING MELODIES BASED ON JUST THE ONE MOTIF?

The way AI generates music in general is similar to the way your email tries to predict the next word for you. So when you write an email, you find it jumps into suggesting what you might want to write next. Similarly, the AI has to learn from a lot of musical data, and it asks what would be the next note given what you just wrote? And if you can predict the next note, then you can predict the next note and the next note and so on. That's the main concept.

But you soon realise with your email that if you start picking up the suggestions for the next word and always write based on what the AI suggests, it doesn't really hold for a long time. And that's what happens with music. If you just give it a starting point and leave it to predict, then it can predict a couple of notes. But after that, it becomes nonsense more or less, and is no longer faithful to the main theme.

So that was the main challenge. How can we let the AI stick to the main theme and develop it? This is where the role of the human expert working with the AI comes in. We had to work with experts to annotate and label a lot of music for us to tell the AI what the theme was and where the development of the theme was in a lot of pieces of music. Basically, the AI learnt as a student. That made a big difference, because then the AI could really keep sticking to the theme.

Also, the AI had to compose the music in a specific musical form. So if you are composing for a scherzo movement or a trio part of the movement or a fugue, each of these musical forms have a specific structure. The AI had to learn how to write a scherzo, how to write a trio, and how to write a fugue.



Ludwig van Beethoven's original sketches (foreground) compared with the notes from the artificial intelligence

"Beethoven's nine symphonies were a small dataset for what the AI needed to do"

DID YOU TRAIN THE AI BY LISTENING EXCLUSIVELY TO BEETHOVEN OR DID YOU USE OTHER COMPOSERS AS WELL?

It was challenging because Beethoven only wrote nine symphonies. That's a small dataset compared to the scale of what the AI needed to do. The way we approached this was to first imagine ourselves like a young Beethoven learning about music. What would he have listened to? So, we trained our first version of the AI as if it was somebody living in the 18th Century listening to baroque music like Bach, as well as Haydn and Mozart. That was the first version of the AI. And then we took that AI and trained it specifically on old Beethoven sonatas, concertos, string quartets and the symphonies.

We first trained the AI to generate the composition as two lines of music, not as a full symphony. So then, we had another AI that would take that composition and learn how to orchestrate it. I believe this is very similar to the way humans learn – you cannot really master fourth level college without going through the first and second and third levels first. It's always incremental.

HOW DID YOU GET THE AI TO TAKE THE MELODY THAT YOU CREATED AND THEN HARMONISE IT AS BEETHOVEN WOULD?

The way we harmonise music is very similar to how we use AI to translate languages. When you use Google Translate or another AI to translate a sentence from one language to another, these models learn a lot of background sentences. So, what is the sentence in German? What is the sentence in English? And from that, they to try to learn how to translate them. So basically, imagine you have these models [for harmonisation]. You put the melody in one side and on the other side you put in how Beethoven would harmonise, so the AI learns how to translate a melody line into harmonised music.

The thing about music is that it's very structured and follows a lot of rules. But this is hard for us to capture and write down. You have to have a PhD in musicology with a speciality in Beethoven to really understand that. But the machine is able to capture that statistically and mathematically in a very implicit way and be able to use that to give us this harmonisation.

WHAT HAS THE RESPONSE BEEN LIKE FROM MUSICIANS AND COMPOSERS?

Their response is really mixed. There are people who loved this very much, and love the idea of having an AI that understands music and can help you finish your composition, or have you explore different musical ideas. But on the other side of the spectrum, there are people who reject even the concept of being able to complete a Beethoven symphony using AI. They are afraid of AI taking their jobs.

IS IT POSSIBLE THAT WE COULD GET AN AI TO MAKE A COMPLETELY ORIGINAL WORK?

Yeah, I have no doubt about that. We did that in visual art a couple of years ago where we developed an almost autonomous AI artist. We had it look at the last 500 years of Western art, then the task was basically to generate new artworks that didn't follow any existing style. If the AI generated an Impressionist or a Picasso kind of art or a Renaissance-style artwork, it could realise and so it would have to learn how to create something new.

The challenge with our project was actually the constraints – the fact that the AI was not generating music by itself but generating music that is based on Beethoven's genius and following the sketches. This makes it more difficult. But I think that generating music autonomously, is an easier task. **SF**

PROF AHMED ELGAMMAL
Ahmed is a professor of computer science at Rutgers University in New Jersey.

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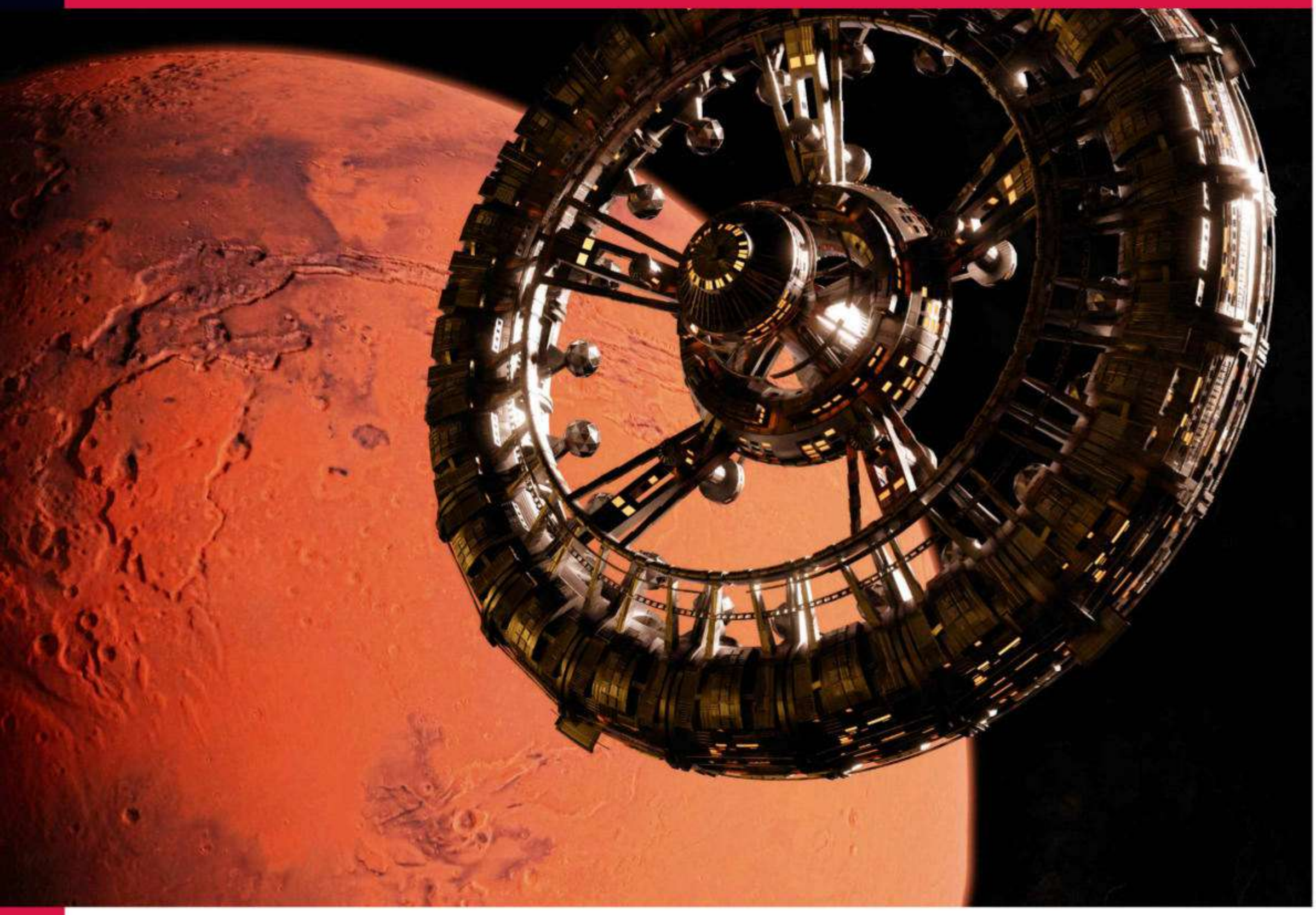
REALITY CHECK

SCIENCE BEHIND THE HEADLINES

Mega spaceship | Facebook smart glasses | Strange celebrity fads



REVIEW

MEGA SPACESHIP: IS IT POSSIBLE FOR CHINA TO BUILD A KILOMETRE-LONG SPACECRAFT?

Buoyed on by its successful Moon missions, China has launched a five-year study to investigate the possibility of building the biggest-ever spacecraft

“It’s about ambition, long-term thinking and instilling a sense of purpose. Such long-haul thinking does not fit in well with shorter-term Western thinking”

BBC *Visit the BBC’s* Reality Check *website at* ***bit.ly/reality_check_*** *or follow them on Twitter* ***@BBCRealityCheck***

The Chinese space programme has been raising eyebrows again – this time because of its proposal to study how to build a large spacecraft, at least one kilometre in length.

To put that into perspective, the International Space Station (ISS) is just 109 metres across, yet it cost $150bn (£110bn approx) and took 30 missions over the course of a decade to build. China’s proposal is for a spacecraft 10 times the size of the ISS. It may sound crazy, but don’t make the mistake of dismissing it just yet.

“It’s about ambition, long-term thinking and instilling a sense of purpose. Such long-haul thinking does not fit in well with shorter-term Western thinking, which might mistakenly dismiss this as propaganda,” explains space writer Brian Harvey, author of the book *China In Space: The Great Leap Forward*.

There is no doubt China has been making serious strides in space exploration recently. The country has returned lunar rock samples to Earth for analysis, making it the third country behind the US and Russia to do so; it has landed a rover on Mars, a feat that only the US had previously managed; and it has made the world’s first landing on the far side of the Moon. On top of this, China is now building the Tiangong space station, which was inhabited for 90 days this year, and is designed to eventually rival the ISS.

Thinking about the future, Harvey points to a Chinese report published in 2009 called Roadmap 2050, which is the blueprint for how China plans to become the world’s leading spacefaring nation by the middle of the century. “The horizon to Chinese spaceflight is not years or decades but half-centuries,” he says.

In other words, this most recent announcement is the beginning of China thinking about how to build such a spacecraft in the future, rather than a declaration that it intends to begin construction.

The idea was floated in a wider call for research proposals from the National Science Foundation of China – a funding agency managed by the country’s Ministry of Science and Technology. It is offering 15m yuan (£1.7m approx) for a five-year feasibility study into new, lightweight designs and materials, and construction techniques in space.

But why would China want a spacecraft 10 times larger than anything that has previously been built? The answer could be artificial gravity. A space station that features artificial gravity would help astronauts stave off some of the most damaging effects of weightlessness, such as muscle wastage and the loss of bone density.

For long-duration trips to Mars or beyond, artificial gravity could make a dramatic difference in keeping the crew healthy.

“Artificial gravity has been this ‘science fiction-y’ holy grail thing for human spaceflight for a century, and the primary way to do it is a large spinning structure,” says Zachary Manchester, an assistant professor at the robotics institute of Carnegie Mellon University, Pennsylvania.

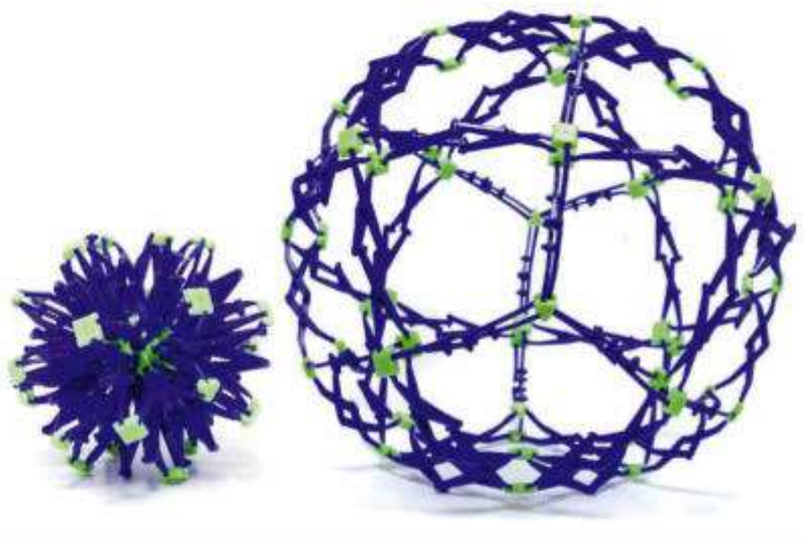
Inside a spinning structure, the centrifugal force makes things move outwards. If the structure spins at the correct rate, this can create a force that mimics the effects of gravity.

The problem with this is that humans are very susceptible to rotation rates. If you spin faster than a couple of revolutions per minute, the average person will start to suffer from motion sickness.

ALAMY X2

LEFT A spacecraft large enough to generate artificial gravity would help astronauts stave off detrimental effects of weightlessness on long-haul trips to Mars and beyond

BELOW Just like the craft in *2001: A Space Odyssey*, the Chinese spaceship could harness centrifugal force to mimic the effects of gravity



One way to launch a huge craft would be to design it so it could fold up like a Hoberman Sphere to fit into a rocket, and expand once deployed in space

However, experiments have shown that these effects virtually disappear at rotation rates of one to two revolutions per minute. So how large would a spacecraft have to be in order to recreate Earth's gravity by spinning at a leisurely one to two revolutions per minute?

"Turns out you need a structure that's about a kilometre across," says Manchester, who received a grant from NASA in February this year so that he and colleagues could study a construction scenario for a one-kilometre-long spacecraft.

Whereas China appears to be looking at how to build something huge in orbit after launching numerous components into space, Manchester is studying whether it would be possible to build a complete structure that would fold into the nose cone of a single large rocket. It would then hugely expand once deployed in space.

The key to this idea is utilising something known as mechanical meta-materials. These use scissor-like joints to fold down to a fraction of their deployed size. The most familiar example of such a mechanical meta-material is the Hoberman Sphere. This child's toy resembles a small spiky ball in its resting state but can expand into a large sphere many times its original diameter.

"It turns out, there are some really interesting mechanisms that you can put together, that can achieve very, very high expansion ratios," says Manchester.

The structures he is studying can expand to hundreds of times their original size. Science 'fiction-y' indeed! Only time will tell if either design will work out, but it's now clear that the world's major spacefaring powers are looking forward to the creation of spacecraft much larger than any we have created to date.

—

by **DR STUART CLARK**

Stuart is an astronomy and astrophysics journalist. His latest book is Beneath The Night *(£14.99, Guardian Faber).*

ANALYSIS

PRIVACY: WHAT ISSUES DO FACEBOOK'S NEW SMART GLASSES RAISE?

The specs enable users to take pictures and record video using cameras embedded in the frames

In September 2021, Facebook and Ray-Ban launched Stories – a pair of smart glasses that allow users to record audio, take pictures and make videos, as well as receive phone calls, listen to music, and look cool all at the same time. But since their launch, various parties have raised concerns about privacy – will the glasses enable users to film others without their knowledge or consent? And who has access to the content once it is uploaded to Facebook or other social media sites?

Stories are essentially ordinary glasses that have speakers built into the frame around the temple near the ears, two cameras located at the top left and right of the bridge, and a three-microphone audio array positioned around the frame. They can be operated through voice control – 'Hey Facebook, make a video', etc – or by tapping a small button on the side of the glasses.

The cameras don't appear to have a zoom function and can take photos at 2,592 x 1,944 pixels and videos at 1,184 x 1,184 pixels, so the quality of the images is significantly lower than what you would get on a typical smartphone. Facebook says that a fully charged frame can locally store as many as 50 videos of up to 30 seconds in length.

Once snapped, photos and recordings taken by the glasses can be edited and shared to Facebook, WhatsApp and other social media platforms with the use of the Facebook View app. So before using your shiny new pair of Ray-Ban Stories specs, you will have to set up a Facebook account or connect your existing account to the glasses. You will then be able to access and edit the material captured with the glasses from your Facebook account. However, there is no option of operating the account using the glasses, so if you lose your shades any potential privacy breaches will be minimal.

ABOVE The Stories glasses look like ordinary Ray-Bans, but come with two cameras, three microphones and speakers

"Once locked in to the Stories ecosystem, Facebook has access to all material you record"

Once locked in to the Stories ecosystem, Facebook has access to all material you record. Because recording is so easy – you literally only have to push one button or make a simple voice command – it's likely there will be many accidental, unwanted recordings. Regardless, Facebook View's privacy policy makes it clear that the company will be able to directly access the material. And of course, anyone with the necessary account will be able to access any uploaded content via social media.

GETTY IMAGES, RAY-BAN/FACEBOOK

When the user is recording, a bright white light on the frame of the glasses will illuminate

But what about the glasses' potential for covert snooping? According to Facebook, the smart part of the glasses can be turned off. This means, Facebook CEO Mark Zuckerberg assures, that the glasses stop recording audio and images. Whether or not this is the case remains uncertain.

It is often relatively easy to see when someone is recording with a smartphone, thanks to the way they hold the device. That is clearly not the case with the smart glasses. Therefore, when the glasses are recording, a little light next to the camera will flash bright white, which will at least give others an indication of when they are being filmed. But it doesn't seem difficult for users to cover up or damage the light.

Then come the legal matters. In Europe, the General Data Protection Regulation (GDPR) regulates how individual users of products such as CCTV cameras and Facebook's Stories glasses use personal information about individuals captured in public places. The law places strict obligations on anyone capturing data using such products, including making it clear that they are doing so, what they are going to use that data for and who they are going to share it with. Some of these obligations can be really challenging to achieve for companies, never mind individual users of products like the Stories glasses.

All things to think about if you ever see someone wearing sunglasses acting a little shady...

by **BART VAN DER SLOOT**

Bart is a researcher who specialises in the issues surrounding privacy and big data. He is an associate professor at the Tilburg Institute for Law, Technology, and Society at the University of Tilburg in the Netherlands. He is the general editor of the privacy journal European Data Protection Law Review.

COMMENT

CELEBRITIES: WHY DO THEY LOVE BIZARRE FADS?

Why are famous stars so drawn to the allure of questionable health products and trends?

In 2019, Josh Brolin, celebrated actor and star of the Marvel Cinematic Universe, ended up with a sunburnt anus.

This unlikely but true sentence was made possible by the bizarre wellness fad of 'perineum sunning' (exposing the patch of skin between the anus and genitals to direct sunlight). It's just one of the countless wellness fads, fashionable diets, and questionable products and procedures that claim to improve your health and appearance that are everywhere in our modern world. Others include 'vampire facials' (injecting your own purified blood into your face), coffee enemas (self-explanatory) and the treasure trove of dubiousness that is Gwyneth Paltrow's Goop company.

Such fads and practices often make grand claims about the health benefits they offer, but seldom offer any robust evidence for them.

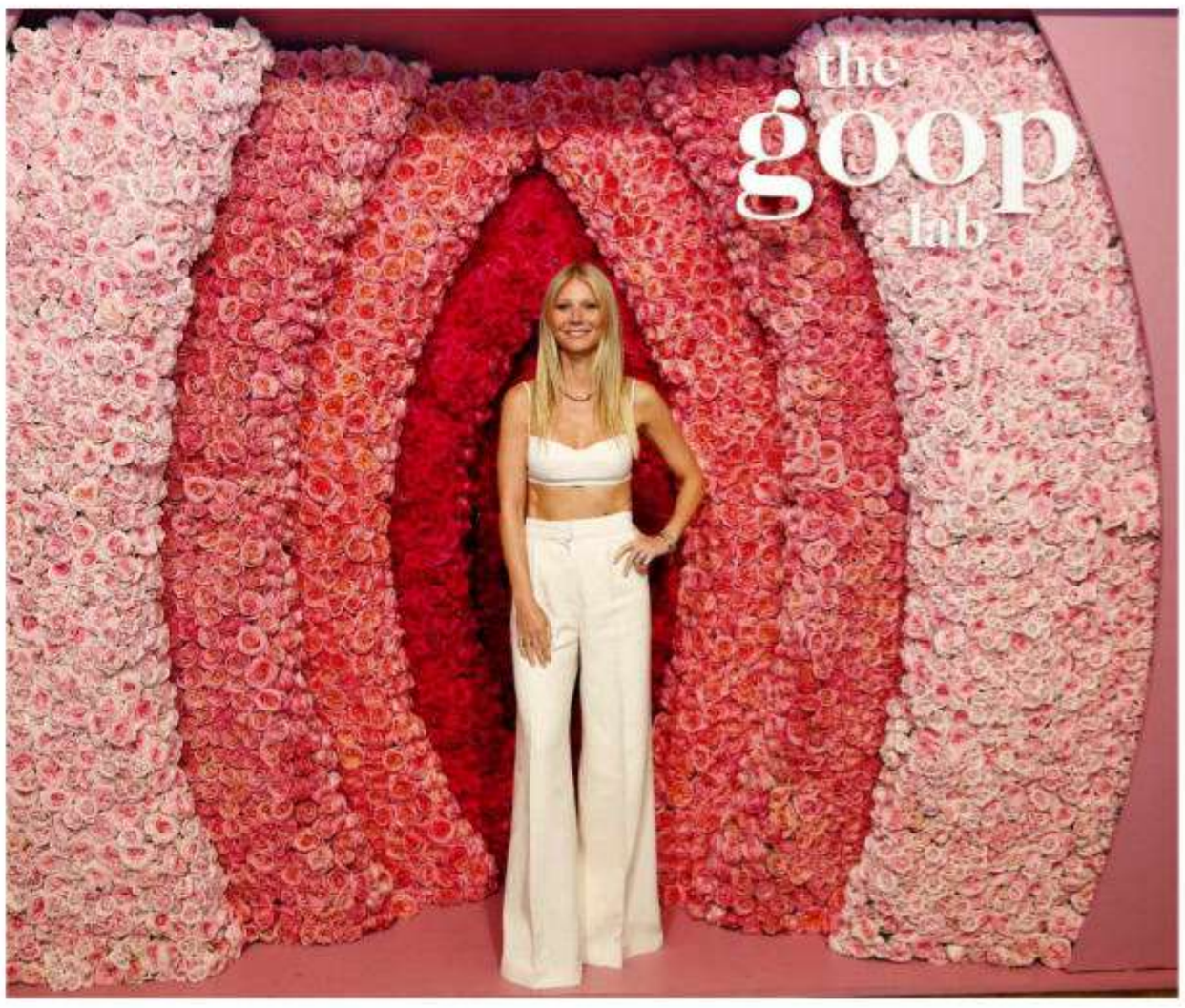
And yet, despite all this, they persist. If anything, they're more popular than ever. It's a bleakly regular occurrence, for an A-list actor, high profile celebrity, and now even Instagram influencer, to claim that they've discovered some new way to improve health, wellness, or restore lost youth. And, despite it typically being extremely unscientific, ridiculous, embarrassing, even actively harmful, and the person advocating having no medical training or expertise whatsoever, countless people embrace it, as if it were the elixir of life and the fountain of eternal youth combined.

This persistent phenomenon, of celebrities having more influence over how people understand health and wellbeing than most doctors, may seem nonsensical, and in many ways it is exactly that, but it's also likely inevitable. There are numerous fundamental properties of our brains that mean celebrity wellness fads are likely to be around for many years to come.

First, the human body is incredibly complex. Doctors have to train for nearly a decade to get to the point where they can competently intervene and improve people's health, and even then there's a lot they don't know. Your average non-medical person will have nowhere near this degree of insight and understanding, so wouldn't necessarily be able to accurately differentiate between helpful health interventions and pseudoscientific fashionable nonsense, particularly when the latter is presented uncritically by 'official' media sources, which they regularly are.

GETTY IMAGES, RAY-BAN/FACEBOOK

"The fact that such wellness fads are blatant nonsense is less important than you'd think. Or hope. Once we've decided to do something, our brains are often reluctant to change course"



ABOVE Gwyneth Paltrow's lifestyle brand, Goop, has come under fire for selling pseudoscientific wellness products

There's also the way the human brain instinctively prefers options that provide the biggest reward for the least effort. Constant exercise, healthy diets, or powerful medications? These are hard work, and/or unpleasant. So, if someone tells you that there's a way to make you healthier that involves less work than the usual methods, a lot of people will subconsciously want to believe it's true, and be motivated to try it out.

The fact that such wellness fads are blatant nonsense is less important than you'd think. Or hope. Once we've decided to do something, our brains are often reluctant to change course or question our choices, even when there's ample evidence that contradicts them.

Granted, many health fads seem far-fetched, even embarrassing. Indeed, many involve inserting weird things on or into our more intimate regions. Shouldn't that put people off? Maybe it does in many cases. But for others, they might make it more convincing.

"Why have I not encountered this before? Oh, because it involves putting things up [insert orifice of choice], and people are too squeamish. Well, not me!" It may seem a bit much, but our brains are often fine with carrying out such mental gymnastics.

Why is it always celebrities who champion these fads? Because such individuals are popular, admired, and even worshipped. Celebrity endorsements are a long-established tool of marketing and advertising. It's important to remember that, for much of our evolutionary history, our main source of information was other humans. This is why, as much as scientific and rationalist types may object, anecdotal evidence is still persuasive, particularly when it's from someone who is 'higher status'. We're inclined to do what they do, own what they own, to make ourselves seem higher status as a result. This is why endorsements work.

We're also more inclined to trust those we're emotionally connected to. While doctors and scientists have rules and regulations about not getting emotionally attached or engaged with others, celebrities have no such limitations, meaning their claims are bound to carry more weight than even the most accomplished expert, in the eyes of the typical person.

And why do celebrities end up creating or embracing such far-fetched fads in the first place? There are many possible reasons, but one is that our thinking and worldview are heavily shaped by the people around us, and what they think and say. Our brains take all this in, and incorporate it into our own conscious processes. However, while I've never been an A-list celebrity myself, it seems to involve being surrounded by people dedicated to your wellbeing, comfort and happiness. Essentially, if your life consists of everyone telling you you're right all the time, you could easily end up with a massively inflated sense of your own wisdom and understanding. Believing and promoting dubious health fads is just one possible outcome of that.

So yes, there are plenty of reasons why health and wellness fads remain popular and widespread, despite being completely contradicted by science. And a lot of this is thanks to how our brains work. So, be aware of this next time you're presented with the latest dubious-sounding claims about how to boost your health or enhance your wellbeing, because you could end up getting burned. And in a very intimate place, too. **SF**

by **DEAN BURNETT**

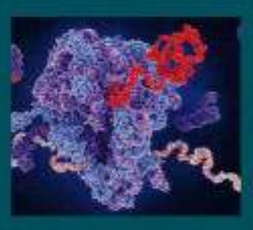
Dean's latest book, Psycho-Logical *(£9.99, Guardian Faber), is out now.*

↗ Send light pollution packing with this smart telescope! p38

INNOVATIONS

PREPARE YOURSELF FOR TOMORROW

AI SCIENTISTS



PROTEIN FOLDING
To understand how a protein works, you need to understand its shape. For decades human scientists have tried to predict what form a protein will take based on its building blocks (amino acids), but last year, DeepMind's AI network AlphaFold solved this problem with astonishing accuracy.

WILDLIFE SURVEY
Want to spend all day counting walruses in photos taken from space? No, we don't either. That's why the British Antarctic Survey has trained an AI to monitor animal populations from satellite imagery.

REWRITING HISTORY
The British Library's National Newspaper Archive has partnered with the Alan Turing Institute to teach an AI to read its library. The AI will scour through the newspapers to try and spot trends and themes associated with the dawn of the Industrial Revolution.

MACHINE LEARNING

Google uses AI to create two-hour weather forecasts

'Nowcasting' could help the UK anticipate catastrophic rainfall events

While the overall accuracy of weather forecasting is actually getting better the more data we have access to, it remains a frustratingly imprecise science that can make us feel like we're always getting caught out. Usually in the rain.

Now, scientists at Google's London-based AI lab DeepMind have tackled this problem head on. They've created an AI forecasting system that aims to let you know the likelihood of rain within the next two hours with much more accuracy, something they call 'nowcasting'.

Traditionally, numerical weather prediction (NWP) systems are used for weather forecasts, which use complex mathematical equations to determine the likelihood of future atmospheric conditions up to two weeks in advance. However, NWP struggles with short-term forecasts of two hours and under. This is where nowcasting can help.

"AI COULD BE A POWERFUL TOOL, ENABLING FORECASTERS TO SPEND LESS TIME TRAWLING THROUGH DATA"

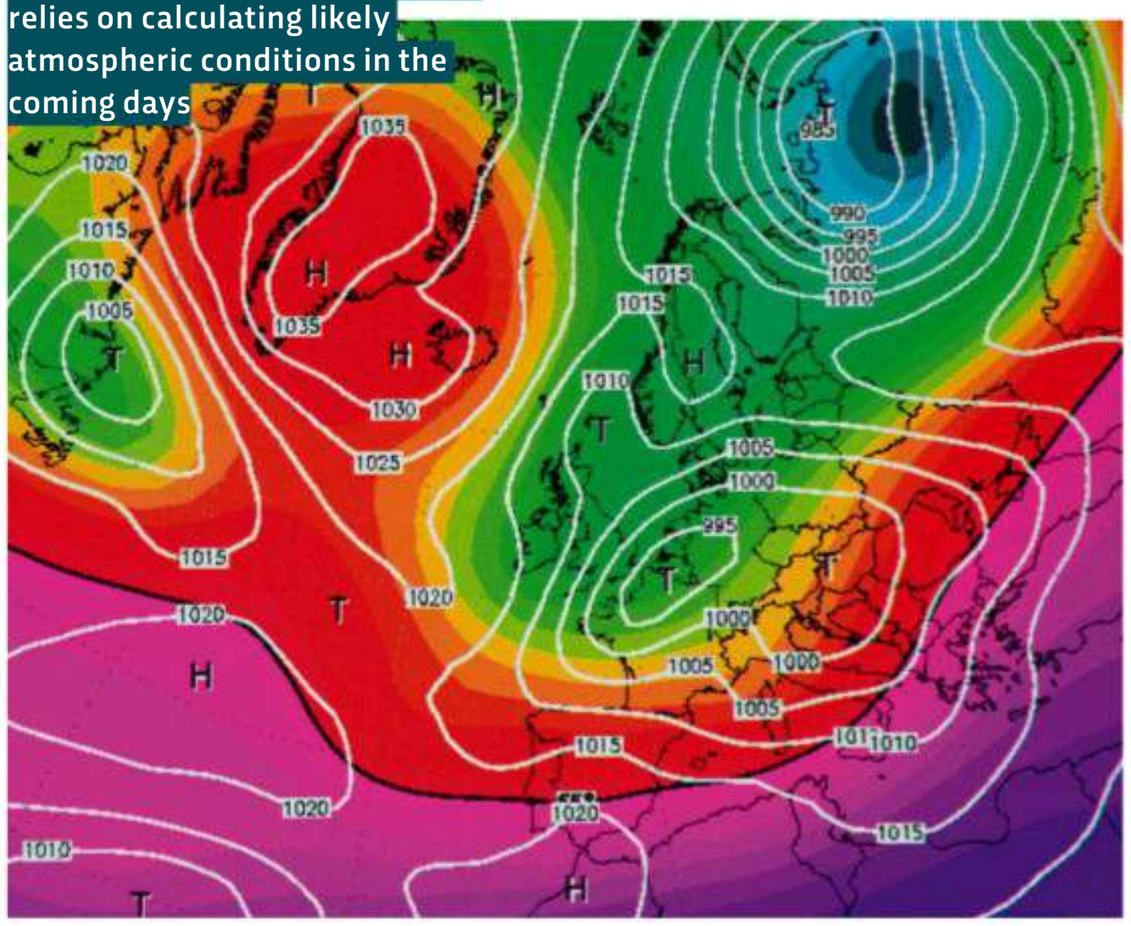
But how does it work? Well, advances in weather sensing have made high-resolution radar information, which measures the amount of precipitation at ground level, available at a much higher frequency. DeepMind combines this data with machine learning to make a more accurate prediction of imminent medium-to-heavy rainfall, including the amount, timing and location.

DeepMind is not alone in researching nowcasting precipitation, but its approach has shown statistically significant improvements in predictions compared to other methods. It works by taking the surface water data from the last 20 minutes and using a deep generative model (DGM) of rain to make detailed, plausible predictions for the next 90 minutes.

DeepMind trained its DGM on the data of precipitation events recorded by radar in the UK between 2016 and 2018. It can now deliver nowcasts in just over a second, and more than 50 expert meteorologists at the Met Office rated DeepMind's approach as their first choice in 89 per cent of cases, when compared to other nowcasting methods.

Speaking of the research, which has been published in the journal *Nature*, DeepMind senior staff scientist Shakir Mohamed said: "It's very early days, but this trial shows that AI could be a powerful tool, enabling forecasters to spend less time trawling through ever growing piles of prediction data and instead focus on better understanding the implications of their forecasts. This will be integral for mitigating the adverse effects of climate change today, supporting adaptation to changing weather patterns and potentially saving lives."

↘
Traditional weather forecasting relies on calculating likely atmospheric conditions in the coming days



CALTECH X2, MIT X2, CARMEL SNOW, GETTYX3, ALAMY

FIRST LOOK

SKY GLASS

Is this the end of the satellite dish?

We take a look Sky's first television, Sky Glass, which looks to shake up how we buy and pay for our TVs and entertainment

WHAT'S THE BIG DEAL?

This is Sky's first TV, which comes with all of its TV services ready to go – no dish or top box required. Plus, there are some decent built-in speakers at the back. You can pay for it in the same way you might buy a smartphone with a phone contract.

DO PEOPLE STILL USE SATELLITE DISHES?

To the Netflix generation, a satellite must seem archaic and that's exactly one of the problems Sky is trying to solve. Everything you used to get through the dish on Sky will now be available over your home Wi-Fi, which means you don't need to get an engineer coming to your house to get started. Sky reckons you should be up and running in a matter of minutes with just one power cable and your Wi-Fi password.

Even better, it comes with installation included, so Sky will deliver the TV, set it up and even take away all of the packaging to be recycled – which is all part of its eco-friendly credentials. This is the first television to be certified carbon neutral.

WILL MY WI-FI BE ABLE TO MANAGE IT?

Sky has built Sky Glass to be very efficient over humble Wi-Fi speeds, so the experience shouldn't be marred by buffering. It also uses the latest Wi-Fi 6 standard, so it won't hog your bandwidth either.

One Sky Glass requires an 11Mbps connection, whereas multi-room will require 30Mbps. Sky reckons 98 per cent of home Wi-Fi connections are already able to manage this, so it shouldn't be a problem for the majority of people.

WHAT HAPPENS IF MY WI-FI GOES DOWN?

This is the Achilles' heel in Sky Glass. It relies on Wi-Fi, and without it, you won't be able to access any of the TV services or recordings. The TV itself will still work of course, so you can use your games console or Blu-ray player. There is a back-up aerial/DTT input in the back for watching standard TV until your Wi-Fi is back up and running.

"CONTENT FROM VARIOUS PARTNERS – INCLUDING NETFLIX, DISNEY+ AND BBC IPLAYER – WILL ALL BE VISIBLE AND ACCESSIBLE ON THE HOME PAGE"

IF I DON'T HAVE A BOX, HOW WILL I RECORD SHOWS?

Your recordings will be stored in the cloud, ready to access whenever you want. Sky has created a new feature in its interface called Playlist, which is where you'll find all your content – it will even pull in other episodes and series of your recorded shows for you to watch on demand. And because it's in the cloud, there are no limits to the number of shows you can record at the same time, and there are no storage limits either.

CAN I ONLY WATCH SKY CONTENT ON SKY GLASS?

No, Sky wants to simplify the way we watch our favourite shows. It's fair to say the act of watching TV has become fragmented in recent years, so we spend a lot of time dipping in and out of different apps looking for something to watch. On Sky Glass, content from various partners – including

Netflix, Amazon Prime Video, Disney+, BBC iPlayer and more – will all be visible and accessible on the home page, alongside Sky exclusives and other TV suggestions. You will need the various subscriptions up and running to access the content, but a Netflix account is included in the Sky Glass base package.

If you like the look of something, you'll be able to click into it and watch it from there – no need to go in and out of separate apps anymore. That applies to the search and voice search functionality too, so it should create a much more fluid, homogenous experience.

BUT IS THE TELLY ACTUALLY ANY GOOD?

Sky Glass is a 4K TV that supports Dolby Vision (as well as HDR10 and HLG for TV broadcasts) and Dolby Atmos. It's an LCD display that uses quantum dot technology, similar to Samsung's flagship TVs. The picture quality isn't going to worry top-range OLEDs out there, but from our brief demo, it certainly looks crisp and vibrant.

IT LOOKS PRETTY CHUNKY...

Compared to the super-slim sets we're used to seeing these days, the design of Sky Glass will look a little unusual. However, as well as simplifying the viewing experience, Sky is also doing its best to simplify things from a hardware perspective too. That means Sky Glass has six built-in speakers that are capable of delivering Dolby Atmos sound, angled around the screen to give added depth and height to the soundtrack. This means you don't need to worry about the faff and cost of an extra soundbar.

There's also a built-in stand for wall mounting, should you wish, and it's available in a choice of five unique colours, each with a brushed finish and colour-matched remote.

As well as black, Sky Glass comes in ceramic white, dusky pink, ocean blue (pictured) and racing green. You can finally match your telly to your decor!

SOUNDS GOOD, HOW MUCH WILL IT COST?

Sky Glass will be available in a choice of three screen sizes, 43-inch (S), 55-inch (M) and 65-inch (L), and cost £649, £849 and £1,049 respectively. They will all have the same specifications, so you'll get the same viewing experience no matter the screen size you choose.

However, instead of paying for it upfront, Sky will offer customers the option of paying for their TV as part of their monthly Sky subscription, a bit like you would a mobile phone contract.

You can choose to pay for your TV over a 24- or 48-month contract, meaning it starts at £13 per month for the 43-inch Sky Glass. You'll then need to add the price of your chosen Sky packages on top of that – the base package costs £26 per month, which includes your subscription to Netflix.

sky.com

Ideas we like...

↓

...a smart telescope that deals with light pollution

Minimum effort, maximum results. Loosely speaking that's the philosophy behind the smart telescope: input the cosmic object you wish to view and the telescope pinpoints its location in the night sky. Then you can enjoy the view via the digital eyepiece or a smartphone app. From there you can take long-exposure images (ideal for deep-sky targets), process your images or share them with the community of fellow astronomers. In particular, this update to the eVscope from Unistellar has added an impressive 'enhanced vision' mode which is designed to help counter the light pollution most of us live under. It's also reportedly easy to set up, and you can even buy a backpack for the eVscope 2 so you can take it into the wilderness to find some dark skies.

Unistellar eVscope 2
£2,599, unistellaroptics.com

↑

...the dawn of the robot butlers

It's happening. It's finally happening. We're getting a robot butler! Okay, so Astro does just look like a tablet on wheels, but Amazon insists that its new bot is more than a roving Alexa. Though it doesn't look very tough, Astro is intended as a kind of personal-assistant-cum-security-guard for your abode. It can go on patrols around allocated zones in your house and will alert you if a balaclava-wearing burglar has broken in, relying on its facial recognition to distinguish familiar faces from strangers. Astro's equipped with a perioscopic camera too, so it can check if you've left the gas on. And if you fancy having a nose around your house while you're at work, you can pilot Astro via your phone. While we're not certain we'd give an Amazon representative a free run of our own house just yet, give Astro a pair of arms and a burning passion to do the washing up and we might be willing to reconsider.

Amazon Astro
$999.99 (£740), amazon.co.uk

↓

...a tough smartphone with a laser rangefinder

Smartphones are hard to tell apart these days, but this new handset from Doogee has a neat party trick. Thanks to a laser and sensor on the top of the phone, it can measure the length, area or volume of a room, up to a scale of 40 metres. It can even do a bit of Pythagoras to calculate diagonals. Inside there's some remarkably good tech – an eight-core processor and 8GB of RAM – and it comes equipped with a reasonably powerful 48-megapixel camera made by Samsung. On the outside this phone is pretty tough. Doogee says it's drop-proof from 1.5 metres, will survive underwater up to a depth of 1.5 metres for 30 minutes, and can function below -55°C… making it the perfect phone for Pingu.

Doogee S97 Pro
£399.99, doogee.cc

←...a projector that works over short distances

If your passion is cinema, nothing beats the drama of projector setup for movie nights. Usually a projector is a pain to use: it needs a large room, clear of anything that could get between it and the screen or wall it's throwing the image at. That's where a short-throw laser projector like the Aura comes in. The Aura can beam out images 254 centimetres across from as little as 20 centimetres away, that screen grows to 381 centimetres from 38 centimetres away. Onboard there are four speakers provided by Harman Kardon (two tweeters and two woofers), Bluetooth and Wi-Fi connectivity and an Android OS for things like Netflix and iPlayer. You can even hook up a gaming console via HDMI.

Xgimi Aura
£2,149, uk.xgimi.com

↑...a VR camera lens

This odd-looking attachment is a first for cameras with interchangeable lenses. Snap it onto one of Canon's compatible cameras, such as the EOS R5, and it records stereoscopic 3D film that you can re-experience with a VR headset. Both lenses record to the single sensor inside the camera, then software inside the camera preps it for VR playback. Right now this tech is quite expensive: you have to subscribe to Canon's software service, the lens itself is £2,099 and an EOS R5 is £4,299.99. But this innovation from Canon is a step in the right direction, as typically you need dedicated kit to record film for VR. Here's to reliving our holidays via virtual reality by the year 2030.

Canon RF 5.2mm F2.8l Dual Fisheye Lens
£2,099, canon.co.uk

↓...an e-bike so fast it breaks UK law

Obviously we would never suggest that you break the law, but that doesn't mean we can't ogle this new 'hyperbike' from the Tesla of bicycles, Vanmoof. The Dutch company says its new bike will top out at 50km/h (31mph). In the UK a pedal-assisted e-bike is legally restricted to only power you to a top speed of 25km/h (15.5mph). Though the company has been coy about what's powering the bike, we do know the bike will have two-wheel drive with motors at each wheel monitored by a traction control system. The extra battery needed to get to this top speed should also mean that the bike will have a huge range too. With similar speed limits in place across Europe and the US, it looks like this model has been built to force a conversation about the current regulation, with Vanmoof hoping e-bikes could entirely replace traditional, petrol scooters in cities around the world.

VanMoof V
£2,998, vanmoof.com

SFP370

BBC **Science Focus** MAGAZINE

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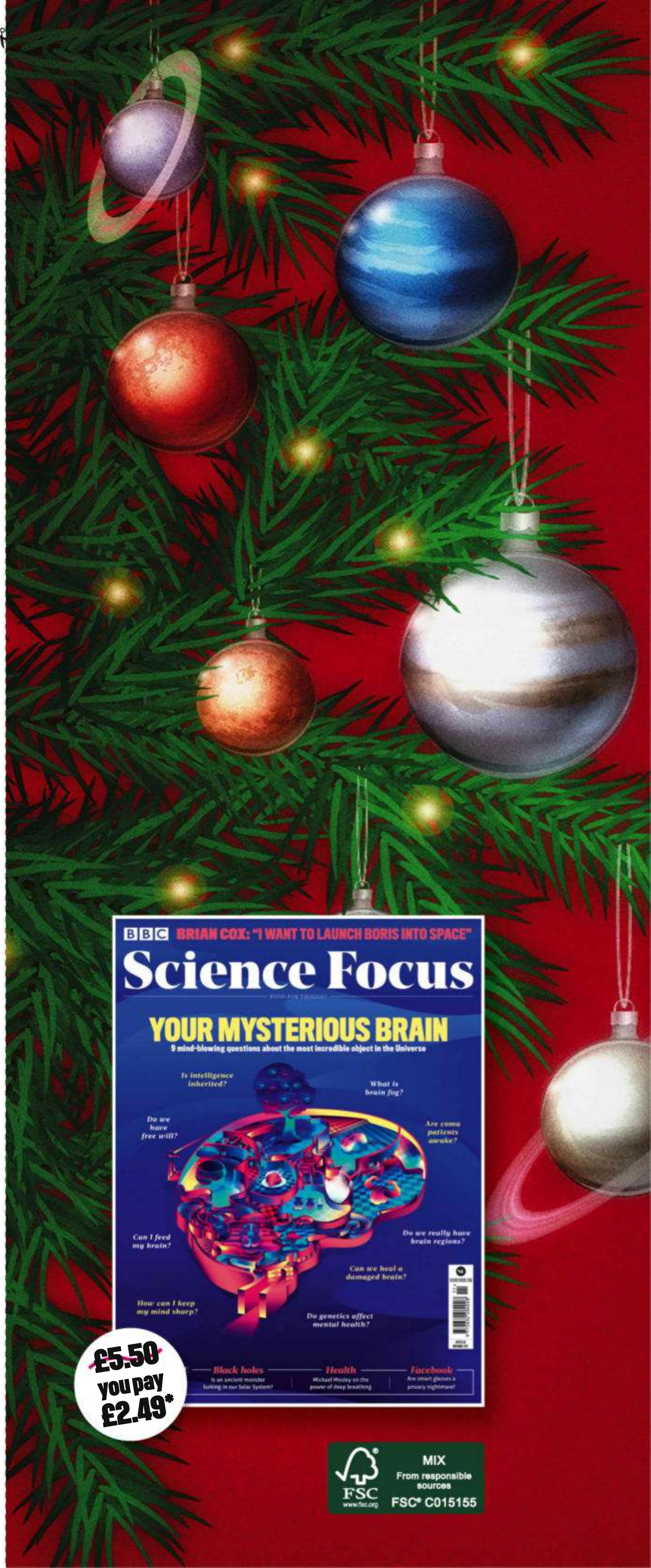
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OCTOPUSES

WITH THREE HEARTS, BLUE BLOOD, EIGHT BENDY ARMS AND INTELLIGENCE THAT OUTSMARTS OTHER SPINELESS ANIMALS, THERE'S NOTHING QUITE LIKE AN OCTOPUS. JOIN US ON A DIVE INTO THEIR WEIRD WORLD...

WORDS: DR HELEN SCALES

BEAUTIFUL BUT DEADLY

Famous for being some of the world's deadliest animals, blue-ringed octopuses are usually quite docile and spend most of their time hiding in rubble and shells. There are between 4 and 10 species in the *Hapalochlaena* genus, living in shallow seas from Australia to Japan. They are all less than a handspan in size, and each has around 60 bright blue rings which flash as a warning when the octopus feels threatened. The rings contain multilayer reflectors, arranged to reflect blue-green light. The flashing is controlled by muscles that pinch in a surrounding layer of black pigmented chromatophore cells that cover the blue iridescence. When the muscles relax the blue iridescence is exposed. The warning flashes come before the octopus deploys its deadly defensive bite. Bacteria living in their salivary glands make tetrodotoxin, TTX, the same toxin that makes pufferfish deadly to eat. Female blue-ringed octopuses cover their eggs in TTX to protect them from getting eaten.

GETTY IMAGES

ON PARADE

↓

SPECTACULARLY SEE-THROUGH

Living in mysterious deep waters down to at least 1,000 metres and with transparent gelatinous bodies, glass octopuses are some of the most elusive and least studied octopuses in the ocean. They've been spotted in tropical and subtropical waters all around the world, usually near giant underwater mountains called seamounts. The one in this picture was found by scientists on the Schmidt Ocean Institute's Research Vessel *Falkor* (named after the Luck Dragon from the 1980s movie *The Neverending Story*) during a 2021 expedition to the Phoenix archipelago in the Pacific. Exploring the deep sea with the remotely operated underwater vehicle, SuBastian, the team also found a second glass octopus. Footage of the two animals was a big hit on the internet.

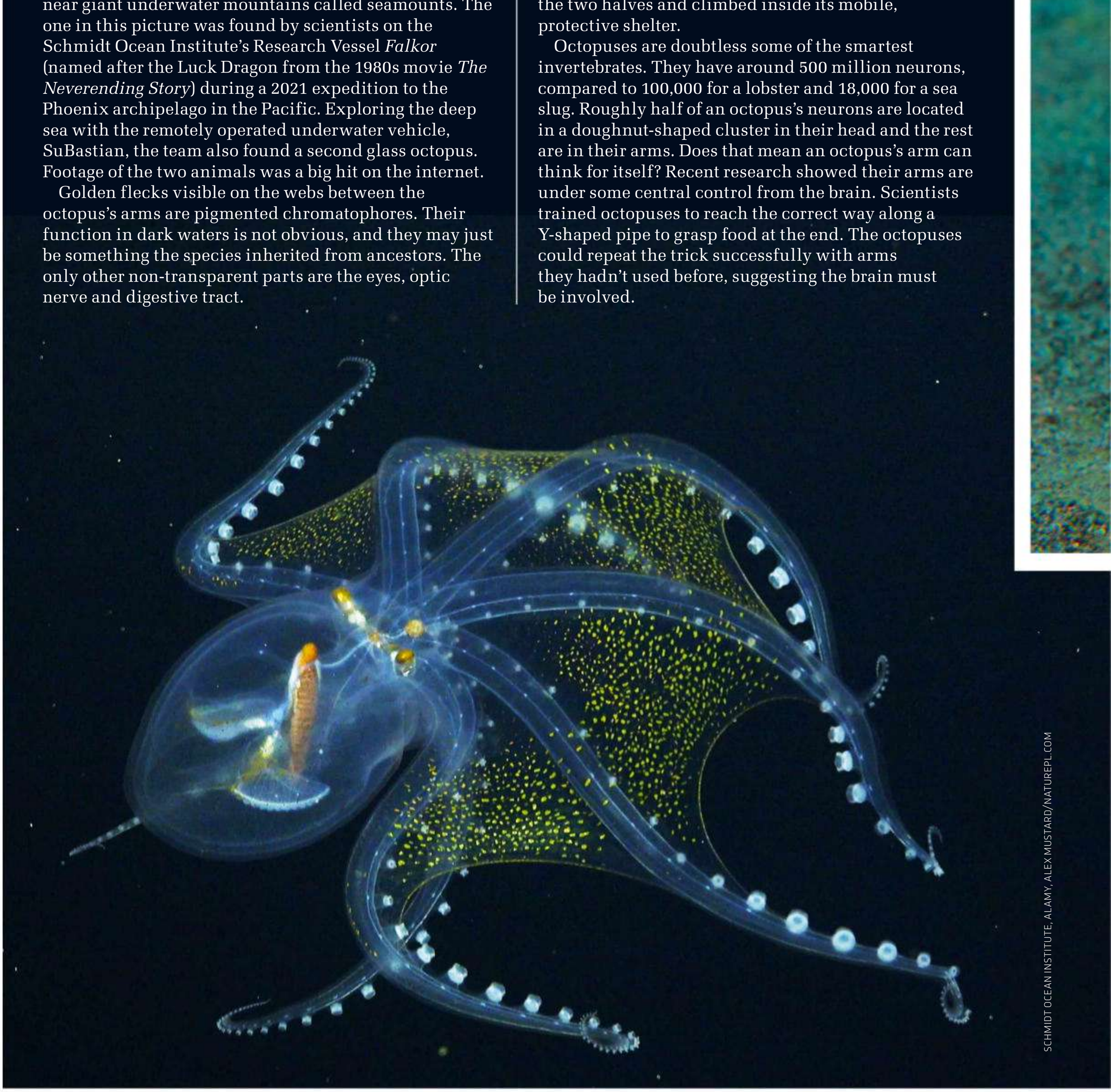
Golden flecks visible on the webs between the octopus's arms are pigmented chromatophores. Their function in dark waters is not obvious, and they may just be something the species inherited from ancestors. The only other non-transparent parts are the eyes, optic nerve and digestive tract.

→

UNDERCOVER OPERATIVE

Working with tools is a well known sign of higher intelligence in animals, as ably demonstrated a few years ago by a video that went viral of an octopus strutting across the seabed carrying half an empty coconut shell. It found another shell, assembled the two halves and climbed inside its mobile, protective shelter.

Octopuses are doubtless some of the smartest invertebrates. They have around 500 million neurons, compared to 100,000 for a lobster and 18,000 for a sea slug. Roughly half of an octopus's neurons are located in a doughnut-shaped cluster in their head and the rest are in their arms. Does that mean an octopus's arm can think for itself? Recent research showed their arms are under some central control from the brain. Scientists trained octopuses to reach the correct way along a Y-shaped pipe to grasp food at the end. The octopuses could repeat the trick successfully with arms they hadn't used before, suggesting the brain must be involved.



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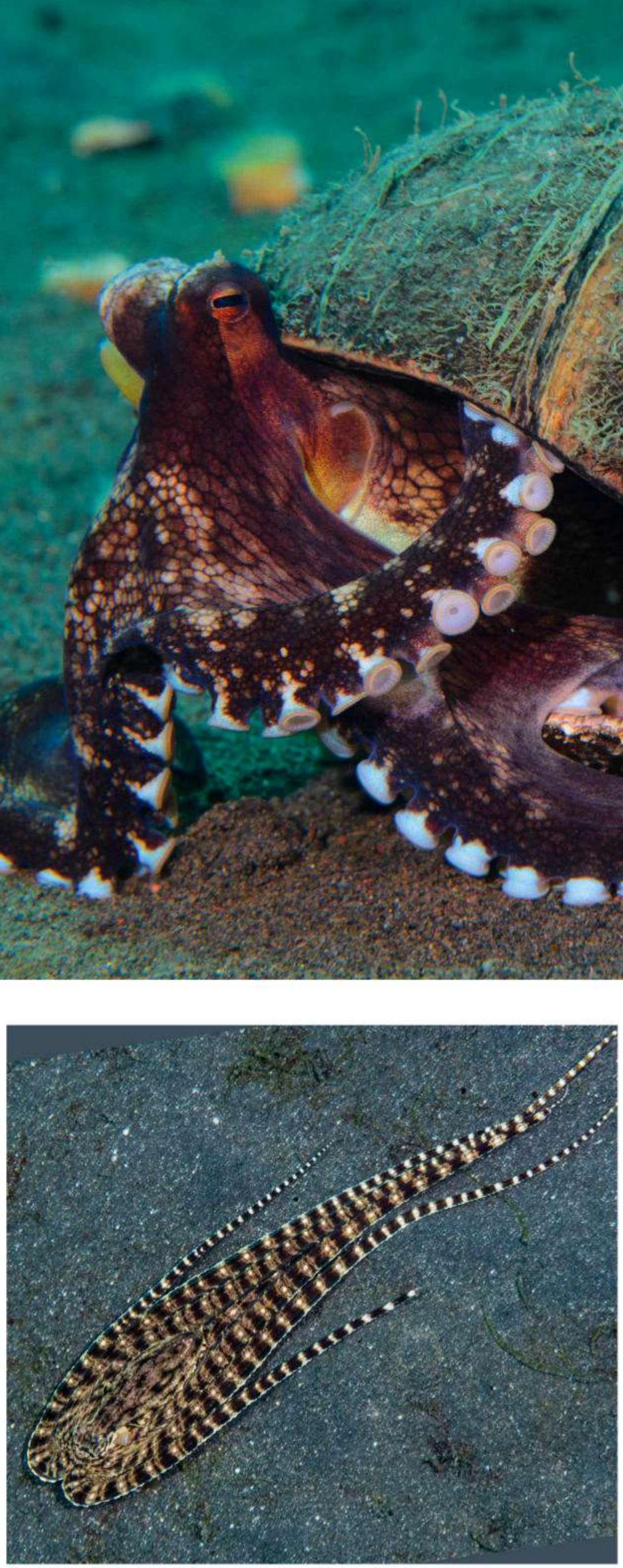

NOPE, NO OCTOPUSES HERE!

The mimic octopus is a true master of disguise. In Indonesia, they have been seen with their arms held together in a leaf shape and swimming across the sand with an undulating motion. This makes them look a lot like a local species of spiny, venomous flatfish, which presumably deceives predators into leaving the soft octopuses alone.

Not content with impersonating just one species, the mimic octopuses have a whole repertoire. They've been seen trailing their arms behind them, possibly mimicking a highly toxic lionfish. A mimic octopus can also turn itself into a sea snake. It stuffs six arms into a hole in the seabed, then sticks out two arms with black and white stripes and waggles them around in a distinctly snaky way. They seem to deploy their versatile powers of deception in response to particular threats. For instance, when attacked by a shoal of territorial damselfish, an octopus was seen putting on its snake 'costume' and the fish left it alone. Sea snakes are common predators of damselfishes.

THE NEXT DISNEY HERO?

Also known as umbrella octopuses, more than a dozen known species of dumbo octopuses all share the same adorable and unusual feature: a pair of flapping, ear-like fins just above their eyes, which they use to swim and steer through underwater currents. They were named after Disney's flying elephant, and most species live near the seabed, alternating between sitting and swimming.

Dumbos are the deepest-dwelling octopuses, all of them with ranges below 1,000 metres. In 2020, one was filmed at just shy of 7,000 metres inside the Java Trench in the Indian Ocean, extending the known maximum depth for octopuses by almost 2,000 metres.

The latest species to be found was collected in a trawl net near the Emperor seamount chain in the Pacific Ocean. The specimen was in amazingly good condition, despite being dragged up thousands of metres. CT and MRI scans showed it had features distinct from all the known species. Scientists named it the Emperor Dumbo.

NOT A NAUTILUS

Argonauts are the only octopuses that make external shells. All the others gave up this ability in the distant evolutionary past, leaving the shell-making to snails, clams and their other molluscan relatives. There are seven known species of these curious little octopuses that occasionally wash up on beaches nestled inside a paper-thin shell (they are also known as paper nautiluses because they vaguely resemble another mollusc, the chambered nautilus).

Victorian scientists puzzled over argonauts. Some thought they weren't shell-makers but piratical rascals that attacked other animals, ate them and made off in their empty shells, floating on the sea and holding two arms in the air to catch the breeze. The truth was revealed in the 1840s by the French marine biologist, Jeanne Villepreux-Power, who discovered argonauts secrete shells from silvery webs on the ends of two arms. She also saw that only females make shells, using them as egg chambers in order to carry their unhatched young with them as they swim through open seas.

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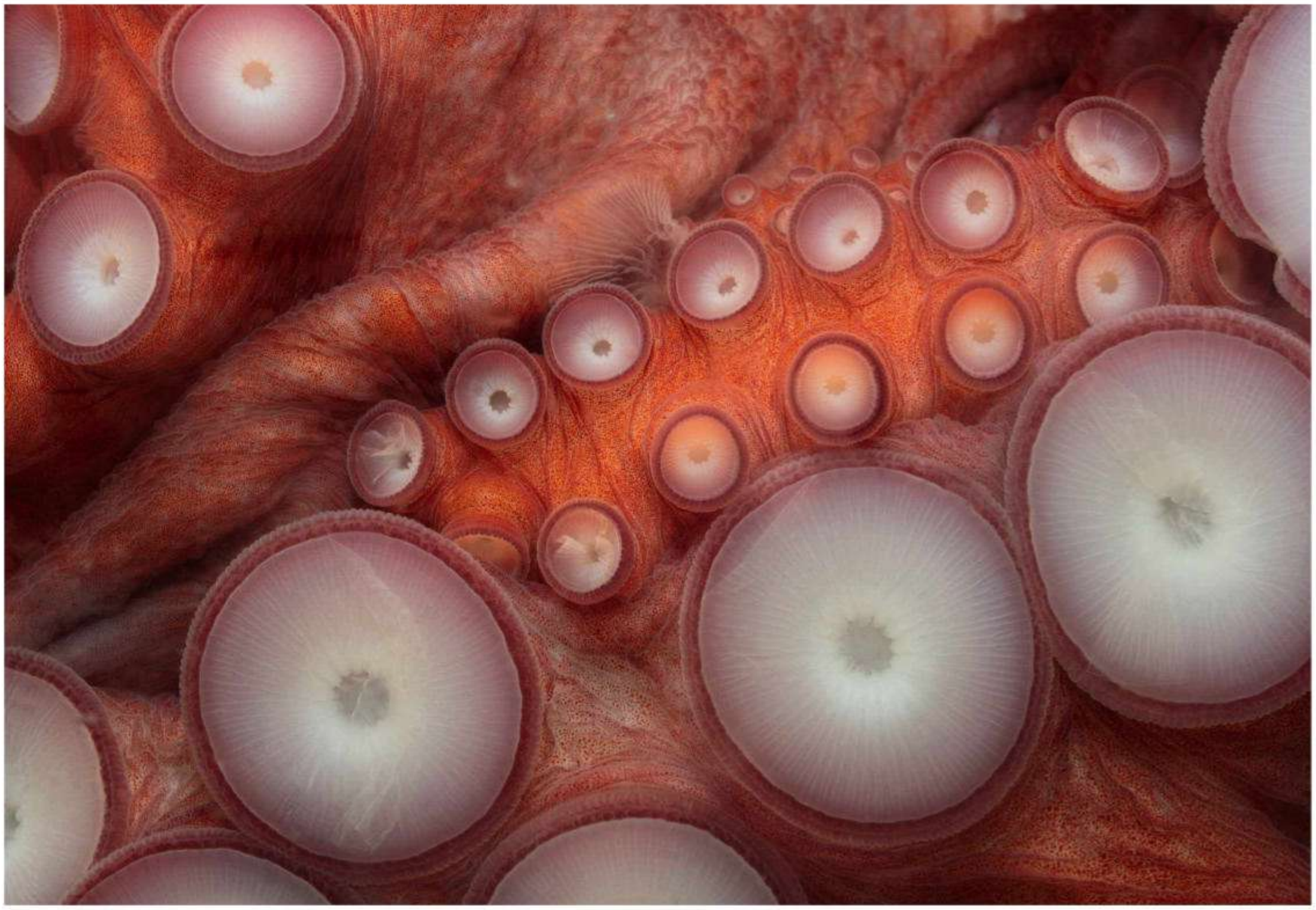

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SERIOUS SUCKER

Of roughly 300 species of octopuses that inhabit seas worldwide, the giant Pacific octopus is one of the largest. Their arms can span as much as six metres and they're covered in suckers as large as six centimetres in diameter, equipped with receptors that allow them to taste things they touch.

We're learning more all the time about the complex lives of octopuses, from rare colonies of many octopuses living together (they're normally solitary and quite hostile towards each other) to the females that throw shells and mud at males that are harassing them. Scientists recently discovered sleeping octopuses change the colour and texture of their skin – quite possibly while they're dreaming. Great mysteries remain, including how octopuses came to be such brainy molluscs with far more sophisticated nervous systems than their close relatives, the clams, oysters, slugs and snails.

by **DR HELEN SCALES**
(@helenscales)
Helen is a marine biologist, writer and broadcaster. Her latest book is The Brilliant Abyss *(£16.99, Bloomsbury Sigma).*

→

FANCY A HUG?

Fluttering membranes decorated with 'peacock eyes' help to make this female blanket octopus look bigger, presumably deterring predators. She can also defend herself by ripping the tentacles off a Portuguese man o' war and waving them around; somehow she is immune to the stings.

Female blanket octopuses grow up to two metres long. And at around 2.4cm, the smaller male in this picture is not to scale. Females can be 40,000 times heavier than the males, which is the biggest size difference between the sexes of any animals.

The male's large eye may help him locate a mate. When he does, he only needs to come briefly into contact with her. He amputates his specialised sperm-bearing arm, the hectocotylus, and gives it to the female. It's likely the male then dies, because none have ever been found with a regenerated arm. A female can store multiple dismembered arms inside her body and uses them to fertilise her eggs, which she carries until they hatch. **SF**

YOUR MYSTERIOUS BRAIN

Science has mapped the surface of Mars and translated the code for life. By comparison, we know next to nothing about what's between our ears. Over the next few pages, we ask leading scientists to answer some of the most important questions about our brains…

ILLUSTRATION: CHRISTINA KALLI

Do we really have free will?

DR LISA FELDMAN BARRETT

Lisa is a professor of psychology at Northeastern University. Her latest book is Seven And A Half Lessons About The Brain *(£14.99, Picador).*

The question of free will is still hotly debated. On the one hand, we clearly experience ourselves as able to make choices and freely act on them. If you fancy some crisps, you can choose to walk into a shop, buy a packet and eat them. Or you can choose to eat a pastry, a salad, or nothing at all. This certainly feels like free will.

On the other hand, neuroscience evidence clearly shows that the brain usually initiates our actions before we're aware of them. Here's what I mean. Your brain's primary task is to regulate the systems of your body to keep you alive and well. But there's a snag: your brain spends its days locked in a dark, silent box (your skull) with no direct access to what's going on inside your body or outside in the world. It receives ongoing information about the state of your body and the world – 'sense data'– from the sensory surfaces of your body (your retina in your eyes, your cochlea in your ears, and so on). These sense data are outcomes of events in the world and inside your body. But your brain does not have access to the events or their causes. It only receives the outcomes. A loud bang, for example, might be thunder, a gunshot, or a drum, and each possible cause means different actions for your brain to launch.

How does your brain figure out the causes of sense data, so that it prepares the best actions? Without direct access to those causes, your brain has to guess. And so, in every moment, your brain remembers past experiences that are similar to your present circumstances, to guess what might happen in the next moment, so it can prepare your body's next action. Guessing (and potentially correcting mistakes) is more efficient than reacting from scratch. These predictions, are, in effect, your brain changing the firing of its own neurons to prepare your body to act, a second or so before the movements actually occur. This predictive process happens completely outside your awareness, but it is continuous throughout your life, and a growing number of scientists are now pretty sure that it's a primary driver of your actions.

From this perspective, your brain's decision to eat a packet of crisps was launched as a plan for action before your brain made itself (you) aware of this plan. So this action, like most of your actions, was guided by predictions that were under the automatic control of your memory and your current surroundings. This description of your brain's inner workings certainly seems to suggest an absence of free will.

And so we arrive at the point where the free will debate has lingered for a long time. We won't settle the debate here, but I'll highlight one puzzle piece that is often ignored. Your brain predicts (in large part) by reassembling your past experiences that are similar to the present moment. That means every new experience you cultivate for yourself – every new thing you read, every new person you talk to, every new thing you learn – is an opportunity to change what your brain will predict in the future, and which actions you may take. In other words, your brain (meaning you) can nudge its future predictions in various directions, right now, by investing in new experiences. You are continually cultivating your past as a means of controlling your future. This may be a form of free will, but it's extended over time and therefore different from how we usually think about free will in the moment. If you practise a skill, whether it's riding a bicycle, or talking to someone who believes things that you abhor, you hone your brain's predictions until that skill becomes automatic and likely to be repeated.

With practice and a little investment of energy, you can make some automatic behaviours more likely than others and have more control over your future actions. Perhaps not as much control as you might want, but more than you might think.

Do genetics affect mental health?

DR DEAN BURNETT

Dean is a neuroscientist and author. His latest book is Psycho-Logical *(£9.99, Guardian Faber).*

“When it comes to things that protect or harm our mental health, the role of our genes is often an afterthought. After all, mental health disorders and issues are products of our minds and brains, whereas our genes are microscopic elements of our DNA. It may seem a bit of a reach to assume that the two are connected.

This is wrong, though. Scientific research has revealed that many mental health disorders have a significant genetic component, which undoubtedly shapes our understanding and treatment of them.

If you step back and look at it logically, it makes perfect sense that our genes would influence our mental health. After all, as intangible as they may be in so many ways, our minds, consciousness, thoughts and emotions are all products of activity in the brain, of the countless complex signals being sent and received by billions of brain cells, also known as neurons. And these signals depend on intricately complicated brain cells working as they should. The good functioning of cells is reliant upon the molecules that make them up. And these molecules, particularly proteins, are determined by our genes.

This means that if there’s a flaw or issue with the code in a specific gene, the molecules it produces won’t be quite the right shape. And for proteins in particular, their shape is a crucial aspect of their ability to interact with other molecules in the appropriate way, which is what they’re for. This means that any cell which has these flawed proteins will be less able to function properly. And if these cells are neurons, then the processes that lead to the formation of our minds can be affected, sometimes in ways that are disruptive, or at least unhelpful.

So, although it’s via several steps, it’s easy to see that our genes can play a role in our mental health. This isn’t to say that they’re the sole factor determining our mental health. It’s not the case that some people have a specific ‘depression gene’ or ‘anxiety mutation’, and that those with these genetic traits develop the eponymous disorder, and those without them never will. In truth, the brain is far too complex for that, particularly when it comes to the parts that result in our mind. There are so many components at work, so many systems combining to give rise to consciousness, and so much redundancy and adaptability in your typical brain, that a single atypical gene automatically producing a (complex and versatile) disorder is extremely unlikely, just like how a single poorly installed circuit in an electricity grid doesn’t inevitably lead to blackout.

However, genetic factors can increase the risk of mental health issues, or make us more vulnerable to developing them, by reducing the brain’s ability to deal with or compensate for traumas and other disruptions. This is presumably why many mental health problems are seemingly hereditary, and why some mental health conditions seem to have similar genetic attributes.

Overall, it’s fair to say that genes play a significant role in our mental health. But so do many other things. And that’s where it gets confusing.”

ILLUSTRATIONS: CHRISTINA KALLI

Can you improve your brain with food?

KIMBERLEY WILSON
Kimberley is a chartered psychologist, author and visiting lecturer, with a degree in nutrition. Her first book, How To Build A Healthy Brain *(£16.99, Yellow Kite), is available now.*

Your brain is hungry. In fact, it is the hungriest organ in your body. Despite making up only around 2 per cent of your overall body weight, your brain consumes about 20 per cent of your body's total energy requirement. But it is a mistake to think that it's only energy that the brain needs to function well; a full complement of micronutrients in sufficient quantities are essential for a healthy brain.

Evidence is growing that deficiencies in these nutrients contribute to poor brain and mental health. Moreover, there is not a single point in the lifespan, from conception to old age, where nutrition doesn't play an important role in brain structure and mental health. For example, we know that it is important for women trying to conceive to take folic acid (a B vitamin) to prevent neural tube defects conditions such as spina bifida. Of course, it's not just folic acid that the developing brain needs. The essential omega-3 fatty acids form the structural building blocks of brain cell membranes. One of these fats, DHA, makes up between 10 and 20 per cent of the brain's total fatty acid content. DHA promotes healthy neuronal morphology and cell signalling, allowing brain cells to communicate efficiently. During pregnancy, accumulation of DHA in the brain and retina is necessary for proper brain development and visual function.

The body is unable to synthesise adequate amounts of DHA, so it must come from the diet. Fortunately, it is abundant in seafood and oily fish such as sardines, mackerel, salmon and trout, and one 140g serving of mackerel supplies enough omega-3 for a week. Consequently, greater maternal seafood consumption during pregnancy is associated with improved brain development and cognitive function in children, including better scores on assessments of verbal intelligence and fine motor control. Lower blood levels of omega-3 in children are connected to poorer behaviour, worse verbal learning and poorer reading skills.

In adults, higher blood levels of DHA are associated with reduced risk of dementia, which is the leading cause of death in the UK. Mild cognitive impairment (MCI) is the age-related decline in cognitive function that can be a precursor to Alzheimer's disease, the dominant form of dementia. A randomised controlled trial of elderly individuals with MCI found that supplementation with B vitamins combined with high blood levels of omega-3s resulted in a 40 per cent slower rate of neuronal atrophy.

The protective effect of omega-3 intake on neurodegeneration is good news, but the bad news is that fish consumption in the UK is below recommended levels. Fewer than 5 per cent of UK children are consuming adequate amounts of oily fish.

Polyphenols are another class of nutrient with profound beneficial effects on brain function. Polyphenol-rich foods include tea, coffee, dark chocolate, berries, herbs, spices and wine. In placebo-controlled trials, polyphenol-rich foods increased brain blood flow and enhanced performance on tests of attention, memory and processing speed.

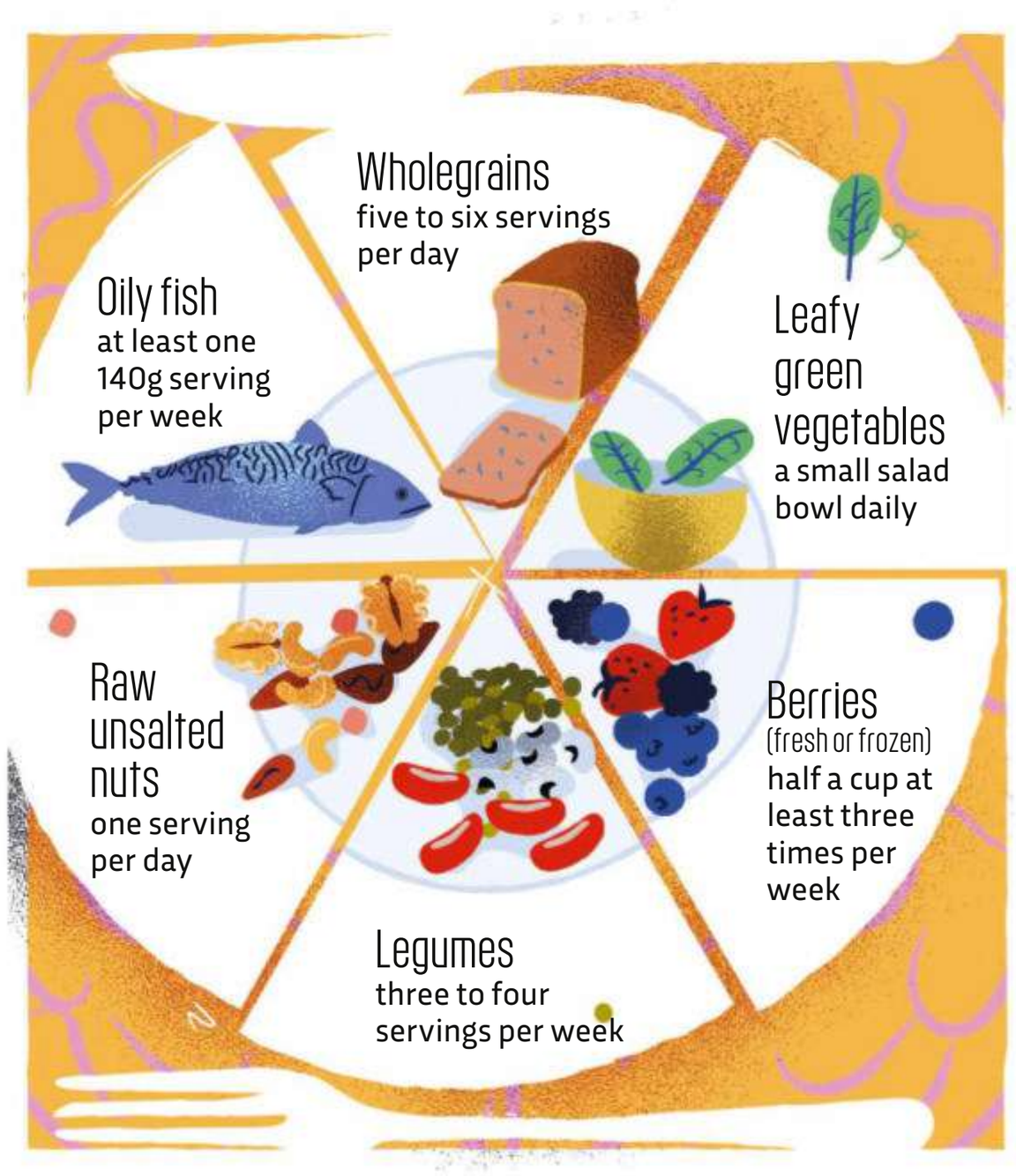
There is even good evidence that improved nutrition can support emotional wellbeing. A landmark Australian study showed that increasing fresh fruits, veg, wholegrains and oily fish in the diet reduced depression severity.

But what about foods to avoid? There seems to be no good news about sugar-sweetened beverages. In healthy young men these drinks rapidly increase markers of inflammation. In animal studies they seem to impair hippocampal function, which has negative effects on learning and memory. Human studies have shown that the typical Western diet can have negative effects on the brain within a week. So we should try to think of sweets, refined cereals, fried food, fast food, processed meats and sugary drinks as 'extras' or 'fun foods' and limit their consumption.

In conclusion, your brain is hungry and not only can you feed it, for the sake of children's brain development and adult mental health, it is imperative that you do.

Brain food

Fill your plate with these to keep your grey matter healthy



What is brain fog?

DR CHRISTIAN JARRETT
Christian is a neuroscientist and deputy editor of Psyche *magazine. His latest book is* Be Who You Want *(£14.99, Robinson).*

If you've ever felt muggy headed, as if you can't concentrate or focus – perhaps you've been forgetful and accident-prone too – then you've experienced what is often termed 'brain fog'. Basically it's a vague and colloquial term for when you feel scatter-brained and mentally impaired.

The term crops up a lot in medical research literature where it's used to capture the experiences of cognitive difficulties described by various patient groups, from people with chronic fatigue syndrome to patients undergoing chemotherapy (for whom it's sometimes dubbed 'chemobrain') to women transitioning to the menopause. Recently, as you have likely heard, COVID-19 has also been blamed for causing brain fog, including in the context of 'long COVID' after the initial infection has actually passed.

Because 'brain fog' is such a catch-all term, it follows that there can be countless possible causes. For instance, there is speculation that the SARS-CoV-2 virus that causes COVID-19 might reach the brain and directly interfere with brain function. Similarly, there is tentative evidence that the drugs used in chemotherapy might have a direct, detrimental physical effect on the brain, thus contributing to brain fog. To take the context of the menopause, it's possible that hormonal changes could directly affect brain function.

However, in all these contexts and others, it's also possible that there are emotional and social contributors to brain fog. For instance, it's telling that many people who have not been infected by coronavirus have nonetheless reported feeling more tired and distracted than usual during the pandemic, perhaps because of the stress and demands of lockdowns and homeworking. Likewise, one of the main causes of chemobrain is thought to be the stress involved in coping with the illness and treatment. When it comes to the menopause too, there could be indirect contributors to brain fog, such as the effects of poor sleep or the general stresses of navigating a challenging phase of life.

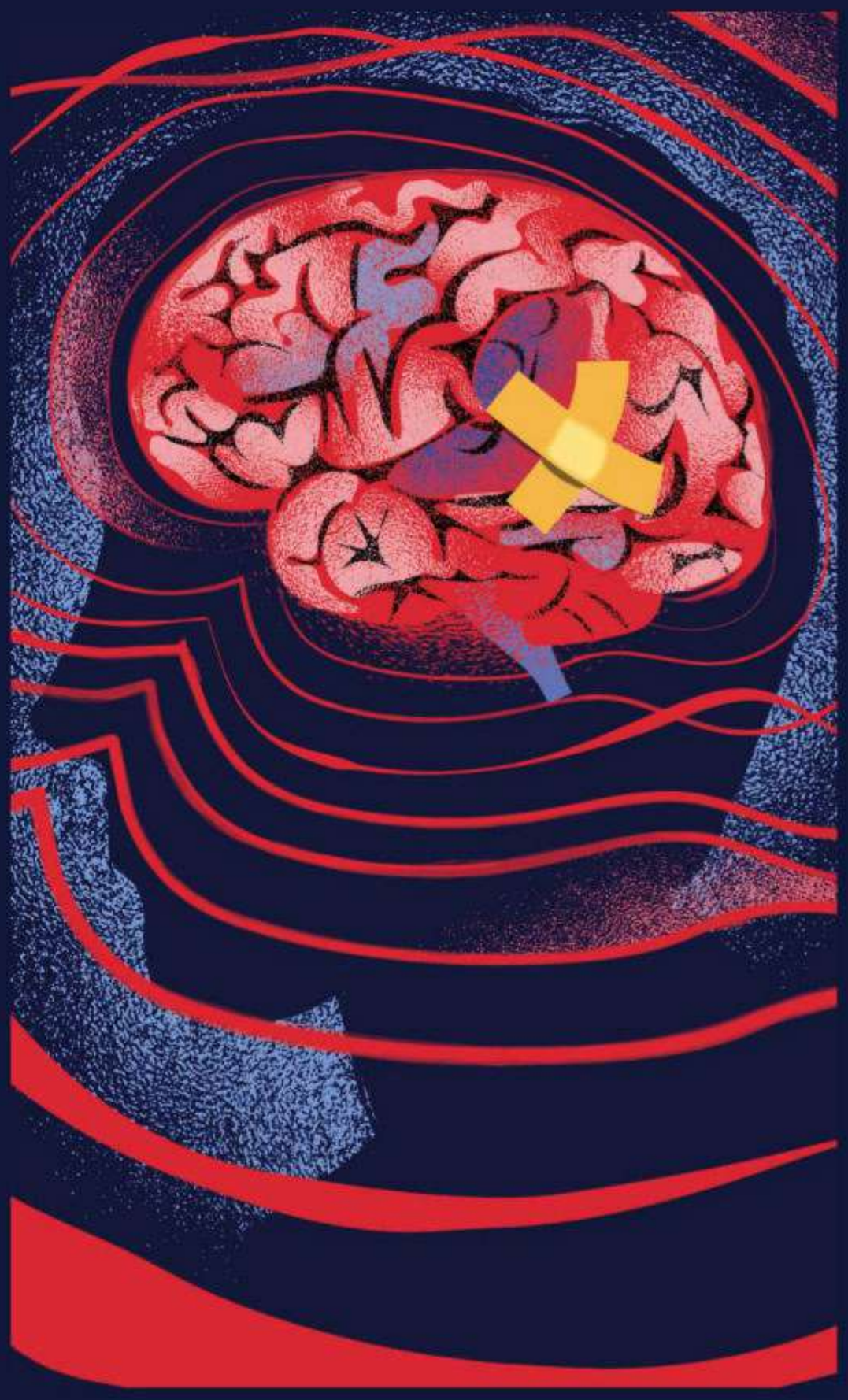
In some situations, such as during pregnancy, the causes of brain fog could even be the mere expectation of mental impairment, fuelled by popular beliefs, rather than there being any underlying direct harmful effect of pregnancy on the brain, or indeed any objective impairment to cognitive function. In this sense, brain fog can be caused by a nocebo effect (a negative placebo effect).

Where the causes of brain fog are due to direct, physically harmful influences on the brain, some of the most effective ways to cope will be compensatory, such as using digital reminders to help support your memory, or making greater use of lists and other planning aids.

If you believe your brain fog might have more psychological or circumstantial causes – perhaps you've been feeling chronically overloaded by having to juggle work responsibilities with parenting, for instance – it might help to make an extra effort to impose some structure on your life, so that you're not constantly multi-tasking. Focusing on one challenge or responsibility at a time will help to clear the fog. Similarly, basic lifestyle changes can improve your mental alertness, such as avoiding too much alcohol and fast food, practising good sleep hygiene (try to establish a regular bedtime routine and avoid working or drinking caffeine too late in the evening), and carving out sufficient time to relax and unwind – even a quick nap could help clear your mind.

As a general rule, when we're in a better mood, our mental performance tends to improve, in part due to feeling more energised and motivated. One implication of that is that anything you can do to improve your mood will likely have knock-on benefits for your mental alertness, from meeting a friend for a chat to taking a walk in the countryside. Indeed, exercise is a well-known mood-booster – aim for a moderate intensity that is fun but not overly arduous. Running, in particular, is fantastic way to optimise your mental function and clear the fog. Martial artists also show heightened cognitive function compared with controls. Find what works for you, but any activity that you enjoy and that gets your heart pumping is likely to help clear that fuzzy-headed feeling.

ILLUSTRATIONS: CHRISTINA KALLI



Can the brain heal itself?

HAYLEY BENNETT
Hayley is a science writer based in Bristol.

Some animals have incredible regenerative abilities, growing new legs and tails to replace lost ones. Fish and salamanders can even grow new brain cells to repair damaged portions of their brains. As mammals, though, our capacity for regeneration is more limited, particularly where the brain is concerned.

"Lower vertebrates keep on replacing neurons quite happily throughout their life, but mammals don't," explains James Fawcett, a neuroscientist at the University of Cambridge. "We stop making new neurons before birth, pretty much, except for one or two small parts of the nervous system."

This means that whilst we can repair a cut to our skin by growing new skin cells, we can't recover from a brain injury in the same way. Instead, our brain's only option is to work with the existing neurons – cells that carry all the information required for us to think, move and perform our normal bodily functions. If the odd brain cell goes offline here or there, it's not usually a problem, but the impact of a major brain injury depends on the type and site of injury, and how many neurons have been lost.

To some extent, what's left can be remodelled – the brain has what we call 'neuroplasticity'. Think of your brain as if it were Google Maps or another route planner. If one of the roads on the quickest route is being dug up, Google Maps will find you another route, even if it takes a bit longer. Similarly, because each brain cell has thousands of different connections, your brain is capable of some fairly extensive re-routing of its signalling, says Mark Ashley, CEO of the US-based Centre for Neuro Skills, which helps patients to recover from brain and spinal cord injuries. "We may lose a highway or two, or several highways, but theoretically, we could find other highways."

This means when the brain is injured it can try to bypass the damaged cells by forming new connections between neurons in order to drive the lost functions. Neuroplastic processes also occur when we're learning new skills, but with a major brain injury it can result in some dramatic remodelling, even to the extent of entire functions being transferred to different parts of the brain – hearing, for example, can be taken over by the visual cortex, and vice versa. Neuroplasticity relies on the nerve cells themselves, as well as support cells called glial cells that help make new connections and repair myelin, which is the protective covering around a nerve fibre that speeds up nerve impulses.

The nerve fibres (axons) that carry the signals do also have some capacity for sprouting new branches, when the main body of the nerve cell is still intact. As Fawcett explains, though, regeneration of nerve fibres that have been cut, as in a typical spinal cord injury, is restricted by the formation of scar tissue – which hinders regrowth – and normal changes during maturation that stop them regenerating their axons. "There's some genetic programme that goes with maturation that turns off regeneration," Fawcett says. His team of researchers have made some headway in regeneration of axons in the spinal cords of mice and rats, but the fibres are much longer and trickier to regrow in humans.

Rehabilitation programmes focus on getting the most out of the brain's natural neuroplasticity and could involve up to 17 hours per day of therapy – the more intensive the better, Ashley says, as this constant 'demand for function' encourages the brain to rebuild in order to respond.

However, our understanding of the brain is limited enough that trying to predict how a patient will recover based on brain imaging can be futile. "I've adopted the notion that the early predictions of recovery are far more likely to be incorrect than correct," says Ashley, who adds that he's often "pleasantly surprised" by what's achievable, given access to the right treatment.

ILLUSTRATIONS: CHRISTINA KALLI

Do we really have brain regions?

DR LISA FELDMAN BARRETT

Lisa is a professor of psychology at Northeastern University. Her latest book is Seven And A Half Lessons About The Brain *(£14.99, Picador).*

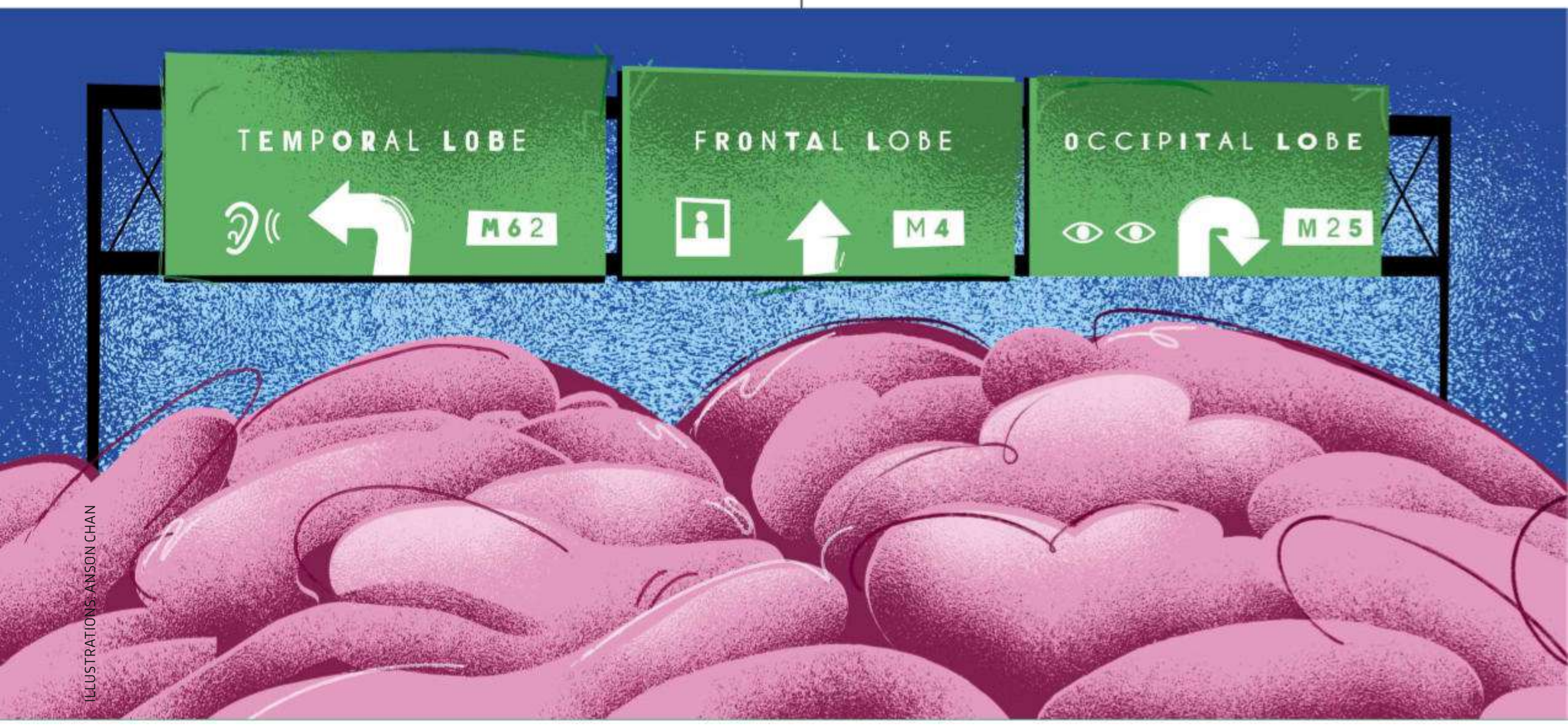
There's more than one way to carve up a human brain. We could draw lines based on what we see with the naked eye: your brain has two hemispheres, left and right. Or we could peer more deeply with a powerful microscope or sophisticated brain-imaging tools: your brain is a network of nearly 200 billion interconnected brain cells. About two-thirds of them, called neurons, continually talk to each other via electrical and chemical signals throughout the network. The other third, called glial cells, have multiple functions that scientists are still learning about.

We could examine a brain structurally. Neurons can be organised in layers, like in the cerebral cortex, which is traditionally divided into different lobes — frontal (at the front), occipital (at the back), temporal (roughly over your ears), and parietal (the rest). Neurons can also be organised into clumps, which scientists call nuclei, that sit beneath the cerebral cortex; for example, you might recognise the name 'amygdala', which is actually a cluster of 13 nuclei deep within each temporal lobe of your brain. We can also carve a brain up by looking at genetic material inside the brain cells, which reveals something about how your brain evolved and how it was assembled when you were a developing embryo.

Another popular way to slice and dice the brain is by function. An obvious approach is to search for the bits of the brain that allow you to think thoughts, feel emotions, see and read these words, hear music, move your arms and legs, and do all the other things that make you who you are. Thousands of studies reveal that this approach has not worked well, because these sorts of functional designations — such as cognition, emotion, perception, action, and so on — do not represent firm boundaries in the brain. The left side of your brain is not the source of logic, and the right side is not the wellspring of creativity. Rationality does not live in your cerebral cortex, and emotions are not lurking in an ancient beast within the subcortical parts of your brain. At this point, it's fairly safe to say that *no psychological function lives in a single part of your brain*. Most of your neurons do more than one thing, psychologically speaking. For example, the parts of your brain most associated with your ability to see, known as the visual cortex (in your occipital lobe), also carry information about hearing and touch. Likewise, some neurons outside of your visual cortex help you to see. Thoughts, emotions, perceptions, imagination, dreams and the rest are better viewed as whole-brain events.

Still, it's possible to carve up a brain by function, but in a different way, based on the information that neurons send and receive. For example, a part of your frontal lobe called the anterior insula routinely plays a role in making your emotions, deciding between options, paying attention to certain things and ignoring others, being aware of yourself, and a host of other mental events. Whatever these neurons are doing, they are always integrating sight, sound, smell, touch, taste, and all the sensations from inside your body, into multisensory summaries that allow your brain to regulate the systems of your body to keep you alive and well.

No matter which way you carve up a brain, it's important to realise that none of these organisations is 'true' in any absolute way. Each organisation is better or worse, depending on the goal you have in mind and what you want to explain. And no organisation alone tells the full story of how your brain, in constant conversation with your body and the world around you, creates your mind.



ILLUSTRATIONS: ANSON CHAN

What is intelligence and is it inherited?

DR DEAN BURNETT
Dean is a neuroscientist and author. His latest book is Psycho-Logical *(£9.99, Guardian Faber).*

Given how it's often discussed and described, particularly in the more brazen and annoying ads for puzzle-based app games, you'd be forgiven for assuming that intelligence is something well understood and easily measured, like your weight or height.

The best habits to keep your brain healthy, happy and sharp

DR CHRISTIAN JARRETT
Christian is a neuroscientist and deputy editor of Psyche *magazine. His latest book is* Be Who You Want *(£14.99, Robinson).*

If you've ever had the feeling that you aren't as sharp as you used to be, it might have given you pause for thought about your brain's fitness and whether it's all downhill from here.

The brain typically finishes developing in our 20s, after which there is a gradual cognitive slowing with age. Later in life, there is also the risk of dementia, caused by diseases such as Alzheimer's. Inevitably, countries with ageing populations are now witnessing rising rates of dementia. Thankfully, cognitive slowing and dementia are influenced by what experts call 'modifiable risk factors'. In short, there are habits you can adopt to maintain your brain's sharpness and protect yourself from the risk of dementia.

Be mentally active

Psychologists and gerontologists refer to a concept known as 'cognitive reserve', which is essentially your brain's ability to adapt in the face of ageing or illness. For instance, if a person has high cognitive reserve, then even if they show some of the biological markers of Alzheimer's (such as the clumps of protein that accumulate and harm brain function), it's possible they will still perform well on tests of their mental performance – it's as if they have spare mental capacity that allows them to cope with the damage. Importantly, there are many activities you can adopt that are considered to build this precious attribute, such as reading, playing musical instruments or singing, completing puzzles, learning a second language and travelling.

Socialise

You will have seen the brain-training apps that purport to keep your grey matter sharp. The problem with these apps is you'll get better at the games, but you won't see your gains spill over into other aspects of your life. They might even be harmful if they divert you from socialising, which is the ultimate brain-training activity. As a team of researchers at the University of Groningen in the Netherlands put it in their recent comprehensive review of this topic, "People with less social participation, less frequent social contact and more feelings of loneliness have an increased risk to develop dementia." Seek out company and lively conversation when you can – it will give your brain a great workout and the feelings of belonging will be a boon for your mental health too.

The truth is far more complicated, confusing, and even controversial. For one, while the dictionary definitions are fairly straightforward, describing intelligence as, for example, 'the ability to acquire and apply knowledge and skills', the *scientific* consensus on what intelligence actually is, regarding how it should be defined and assessed, is still disputed.

For a lot of recent scientific history, there was much debate as to how many intelligences the human brain possessed. As in, do we have one general intelligence that does everything, or several different types of intelligence that are used for more specific tasks? Like spatial intelligence, musical intelligence, linguistic intelligence, and so on.

Both models were the subject of much study. At present, evidence leans more in favour of us only having the one general intelligence, but as ever, the picture is more nuanced than that.

Distinctions can also be drawn between fluid and crystallised intelligence. The latter is the information you know and have access to, stored as memories in your brain. The former is your ability to use and apply information, whether derived from memory, or from what you're perceiving in the moment. A professional quizzer who wins contests thanks to their vast general knowledge is utilising impressive crystallised intelligence. Alternatively, Sherlock Holmes, who uses the information available from a crime scene, combines it with what he's got in his head, and applies it to a situation to work out solutions and explanations, is relying more on fluid intelligence. In a sense, crystallised and fluid intelligence are like your computer's hard drive and CPU, respectively.

Evidence suggests that crystallised intelligence keeps building up for as long as we've got a working brain, while fluid intelligence declines as we get older, as the complex but intricate parts of our brain that support it wear down over time.

While there is still much debate over what intelligence actually means, few dispute that your genes play an important part. This isn't to say that there is an established intelligence gene, which directly determines how smart you'll end up being. Our environment, upbringing, education and experiences all shape our adult intellect.

But even so, our genes clearly play a role. Exactly what this role is remains to be pinned down, but it's undeniable that intelligence has a hereditary component, meaning your eventual intelligence will skew towards that of your biological parents, even if you have a substantially different upbringing (by being adopted, for example). There's also the surreal link between height and intelligence, meaning tall people tend to be more intelligent on average.

Of course, one of the reasons it's hard to be specific or certain is because intelligence it so hard to pin down and measure. You might be surprised about this, because isn't that what we have IQ tests for? Technically yes, but the use and application of IQ tests has long been mired in controversy, given how no two scientists can seemingly 100 per cent agree on what intelligence actually is. And there have long been scandals and problems with IQ tests, largely because they're created by scientists who are prey to their own biases and prejudices.

Nobody is arguing that intelligence isn't a thing, it's just that there's a lot of debate around what sort of thing it is, how it works, how it's influenced, and how it should be measured. About the only thing anyone can agree on is this; IQ and intelligence definitely can't be determined by how well you do on a rudimentary puzzle game, no matter how many ads for apps insist otherwise.

Exercise often

Your brain depends on oxygen and other nutrients to function well and so it follows that the better your cardiovascular health, the fitter and healthier your brain will be too. At the same time, a sedentary lifestyle and obesity are both associated with speedier cognitive decline and an increased risk of dementia. So, try to build an active lifestyle into your routine. Running, cycling, swimming or similar exercise classes will do the trick, but if that's not your thing, you could try regularly walking, or taking the stairs more often. You can even stay more active through gardening or frequently taking part in some other kind of hobby that gets your heart pumping, such as dancing or choir singing.

Eat healthily

It's good for your brain if you can sustain a healthy diet. Plenty of fruits and green vegetables will provide your body with ample antioxidants that help cleanse the brain of 'free radicals' – a kind of harmful by-product of various biological processes. To meet these goals, the World Health Organization recommends the so-called 'Mediterranean Diet', which is high in fruit, vegetables, legumes (such as lentils, beans and peas), nuts, cereals, fish and olive oil, while being low in saturated fats, sugary foods and meat. If that's all a bit too overwhelming, make a start by aiming to eat one more item of fruit a day and avoiding too many takeaways or supermarket ready meals. Read more about healthy eating for your brain on p54.

Stay curious

Perhaps surprisingly, there are links between personality and brain health. People who score higher in Openness to Experience (one of the so-called 'Big Five' traits that's associated with curiosity, creativity and a willingness to try out new things) tend to be sharper and at lower risk of dementia. As a team at the University of Georgia put it, "Higher Openness was related to better psychomotor speed, cognitive flexibility, and working memory in depressed and non-depressed older adults." There are habits you can adopt to boost your Openness to Experience, such as seeking out more awe (by taking walks in stunning surroundings or watching nature documentaries), travelling to unfamiliar places, and enjoying mind-expanding cultural experiences (such as live theatre).

Think positive

Once you've established the range of positive habits suggested here, you'll hopefully be feeling optimistic about your brain's future, especially as you get older. This is the final piece of the jigsaw because a growing amount of research suggests that your attitudes toward ageing can have real consequences for your neural health. If you expect to become slow and forgetful, that could well become a self-fulfilling prophecy. But if you realise that your brain health is to some extent in your own hands, and that's it's possible – with the right lifestyle and routines – to remain mentally agile through life, then that's likely to benefit your brain. So, seek out positive older role models if you can, and seize the chance to train your brain like a muscle – you may yet unlock your full potential.

ILLUSTRATIONS: CHRISTINA KALLI

Are people in comas conscious?

DR ADRIAN M OWEN

Adrian is a British neuroscientist working in Canada. He is the author of Into The Grey Zone: A Neuroscientist Explores The Border Between Life And Death *(£16.99, Guardian Faber).*

In July 2005, Carol was hit by two cars while crossing a busy road. She survived, but suffered a massive brain injury, which left her in a vegetative state with little hope of meaningful recovery. Carol's life would never be the same again. Two cars and a moment's distraction had redefined the rest of her existence; a shocking reminder of how vulnerable we are, and how the trajectory of our lives can change in an instant.

The vegetative state is often described as 'wakefulness without awareness'. These patients open their eyes and will often have sleeping and waking cycles, although they remain non-responsive to any form of external prompting or stimulation. They are both 'there' and 'not there', lingering in the indeterminate space between life and death. For decades, it was assumed that such patients lack any awareness, including who they are, where they are, and the predicament they are in.

Several months after her accident, we put Carol into a fMRI scanner at Addenbrooke's Hospital, Cambridge, and asked her to imagine waving her arms in the air, as if she was playing a vigorous game of tennis. Amazingly, a part of her brain known as the premotor cortex 'lit up' in exactly the same way as it does in healthy people, when asked to imagine the same series of actions in the scanner. This startling result told us that Carol must have understood the instructions and, furthermore, she had been able to turn them into a response; not a physical response, like squeezing a hand or blinking an eye, but a *conscious brain response* that confirmed beyond doubt that Carol was not vegetative at all, but conscious and aware, even though she had been physically non-responsive for more than five months.

After a few more years of scientific tinkering, we took the technique one stage further and successfully communicated with a young man called Scott who had been apparently vegetative for 12 years following a near-fatal collision with a police car. By changing his pattern of brain activity in the scanner to indicate a 'yes' or a 'no', Scott was able to tell us that he knew where he was, how long he'd been there, what he enjoyed watching on TV, and whether or not he was in any pain (he wasn't). Nevertheless, at the bedside, Scott remained non-responsive whenever he was examined by his doctors and care staff.

By 2016, more than 1,000 patients around the world had been scanned using variations on the brain-imaging technique we had developed, and an independent scientific review concluded that between 20 and 25 per cent of them were like Carol and Scott; conscious and aware, despite their outward appearance, trapped in their immobile bodies, listening silently to every conversation at their bedside, and every decision that had ever been made on their behalf. While no one knows exactly how many vegetative-state patients there are in the world (in the United States, it has been estimated that there are between 15,000 and 40,000), these figures confirm that hundreds of thousands of them may not be what they appear to be at all.

Despite this astonishing series of discoveries, the various regulatory bodies that determine whether the findings will be used to benefit the lives of all patients with 'disorders of consciousness', like the vegetative state, continue to drag their feet. Earlier this year, the Royal College of Physicians revised the UK guidelines on the management of these patients, stating that "once a patient is in a prolonged disorder of consciousness … repeat imaging is not routinely required".

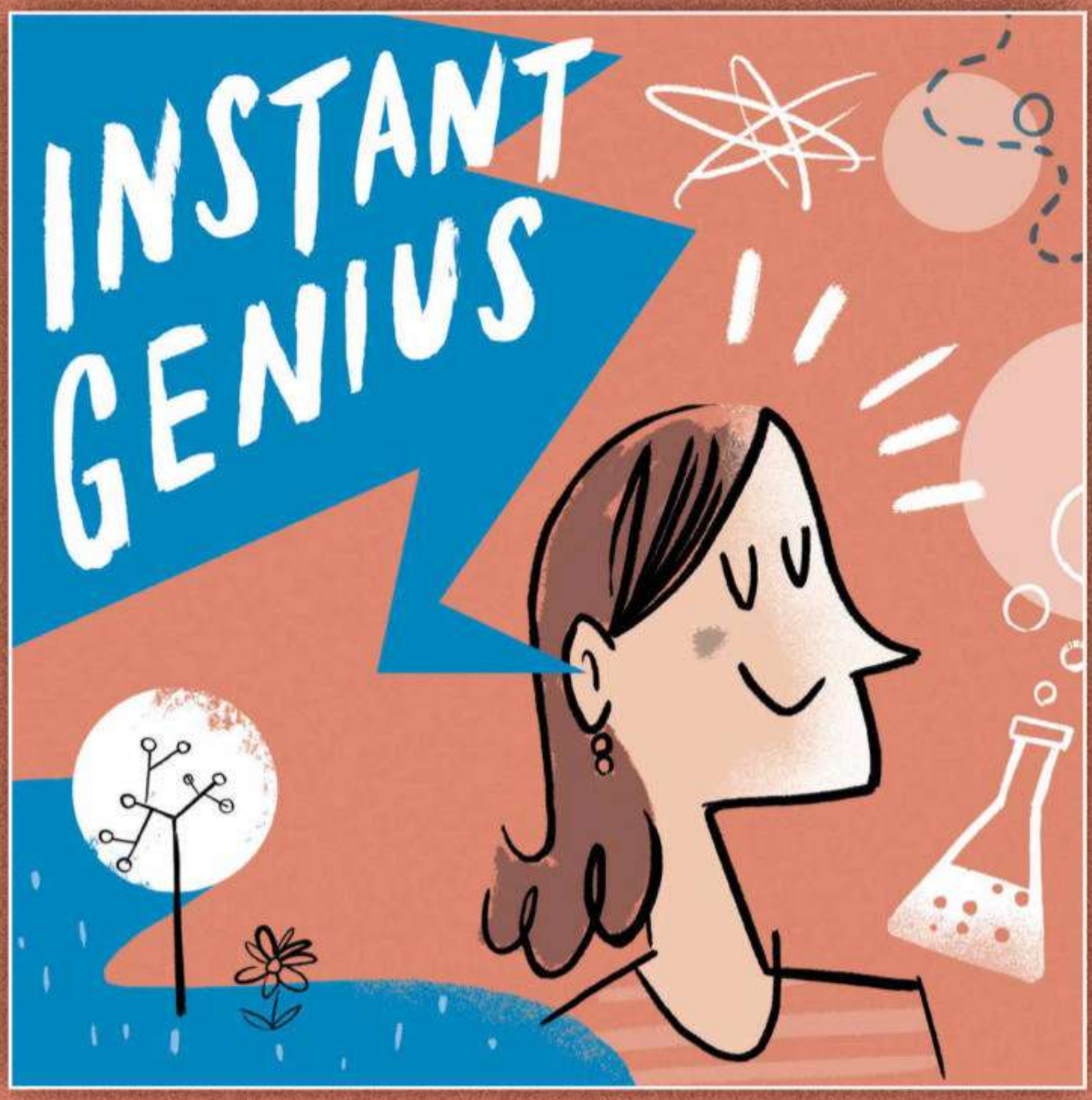
For too many years, patients who are diagnosed as being in a vegetative state have been warehoused – an unfortunate term that is frequently used to describe how they are often 'written off', denied the expertise of professionals who can carefully assess their mental functioning over time and spot subtle signs of emerging awareness. Yet we now know that many of these patients have been completely conscious all along. This thought still makes me immensely uncomfortable.

To fail to test for consciousness using technologies like fMRI is to deprive tens of thousands of brain-injured patients worldwide of an important benefit: the opportunity to make themselves heard, to communicate with their clinical team and their relatives, and to contribute to decisions about life-preserving treatment, rehabilitation and other interventions. By failing to make these scans available, we abandon them. They are voiceless, yet we have created technologies that can give them a voice. It is high time we allow them access to these technologies so they might once again take their place among us in the land of the living. SF

ILLUSTRATIONS: CHRISTINA KALLI

DON'T JUST READ THIS MAGAZINE... LISTEN TO US TOO

The all-new weekly podcast from the team behind *BBC Science Focus*



FEATURING

THE BIG BANG
with ***Prof Jim Al-Khalili***

THE NEANDERTHALS
with ***Dr Rebecca Wragg-Sykes***

CALORIES
with ***Dr Giles Yeo***

FORENSICS
with ***Prof Sue Black***

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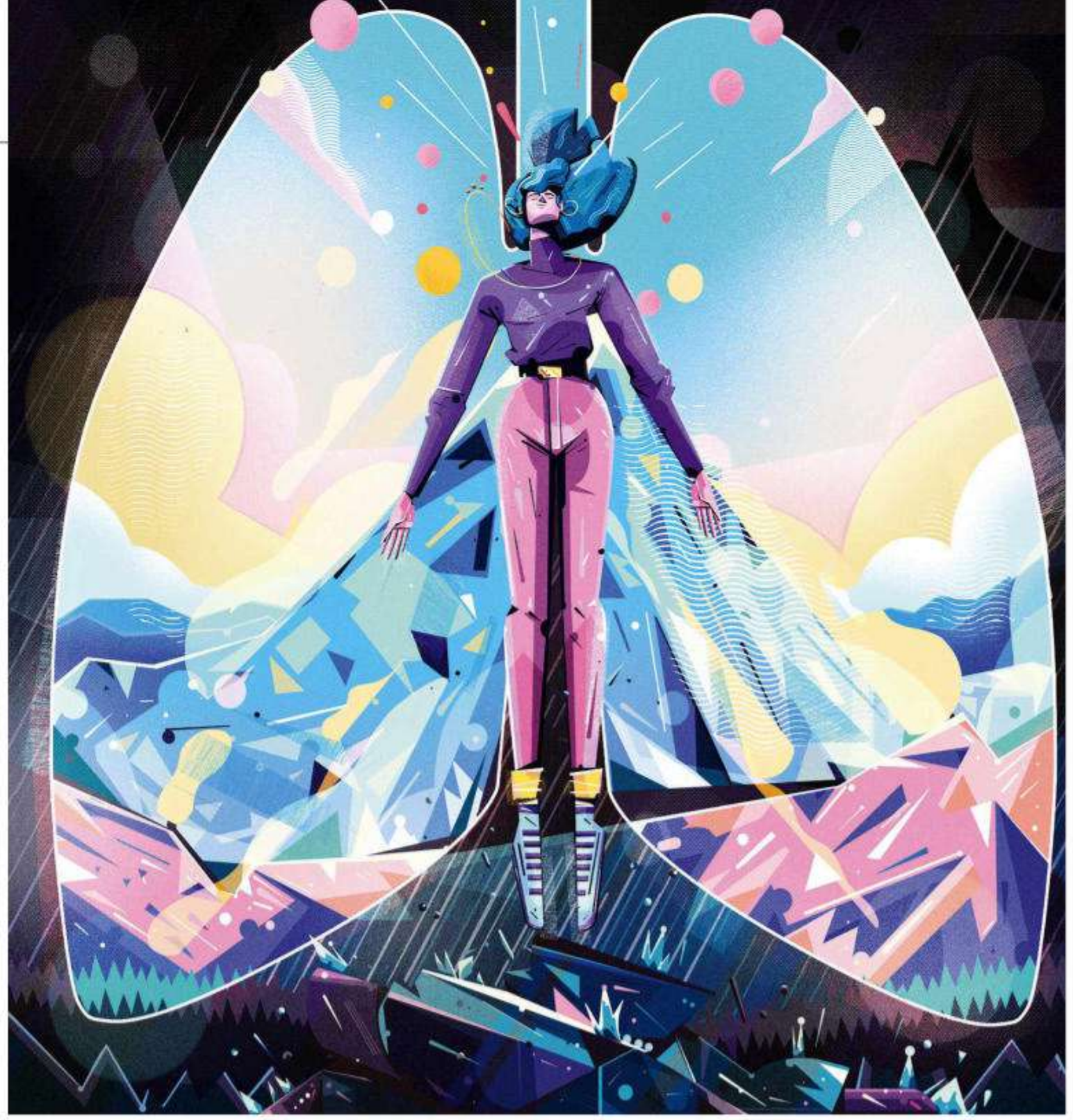
COMMENT

BREATHE IN... AND OUT

Deep breathing isn't just for yogis. Evidence suggests it can soothe anxiety, help you sleep and even ease your pain



My new podcast series, *Just One Thing*, which has featured in this magazine before, has proven to be an unexpected hit, with millions of downloads. If you haven't heard it, the idea is very simple. In each episode (which lasts just 15 minutes) I explore one thing you can try that could make a big difference to your life. The list of subjects I've covered so far includes things like cold showers, early morning walks and eating fermented foods.

One of the things that has made a big difference to my life, and which is very simple to do, is to practise a bit of deep breathing. When I feel stressed or when I'm awake in the middle of the night and struggling to go back to sleep, which is quite common, I do a breathing exercise called 4-2-4.

I breathe in for a count of four, hold it for two, then breathe out to a count of four.

According to Ian Robertson, a psychology professor at Trinity College, Dublin, who features in that podcast, deep breathing "is the most precise pharmaceutical you could ever give yourself, side effect free." He also pointed out to me that it's very discreet. "You can do it in a meeting and nobody need know you're doing it."

"Deep breathing switches on your parasympathetic nervous system, which acts like a brake, calming your body down"

Deep breathing switches on your parasympathetic nervous system, which acts like a brake, calming your body down. Long, deep breaths will slow your heart and also reduce your blood pressure. That way it reduces anxiety.

Deep breathing can also be an effective way of dealing with pain. Chronic pain is closely linked to stress and learning how to do 'controlled breathing' is an important part of treatment for managing both. That's partly because pain and stress have a similar effect on the body. They increase your heart rate and blood pressure, make breathing faster and shallower, and cause muscles to tighten up. If you live in a state of chronic stress or pain, your nervous system will stay on permanent high alert, with your muscles in a constant state of tension.

And it's not just your body. Stress and pain make your levels of stress hormones surge, which in turn will keep your brain in a state of constant arousal. You'll be more sensitive to pain signals and much more aware of them. One way to help break this vicious circle is to practise deep-breathing exercises.

As well as 4-2-4 you might want to try 3-4-5 breathing. In this case you inhale slowly through your nose to a count of three, then hold for four, before exhaling for five. You can do this any time you feel stressed or in pain. Repeat the breathing cycle 10 times and you should feel yourself relaxing.

So next time you're feeling under pressure, remember you have the power to change your brain chemistry with a few deep breaths, whenever and wherever you like. SF

PORTRAIT: KATE COPELAND ILLUSTRATION: JOE WALDRON

MICHAEL MOSLEY

Michael is a writer and broadcaster, who presents *Trust Me, I'm A Doctor.* His latest book is *COVID-19: Everything You Need To Know About Coronavirus And The Race For The Vaccine* (£6.99, Short Books).

BBC TWO

COMMENT

THE NEW WORLD OF WORK

We shouldn't have to force ourselves to contend with a commute or an office, if they no longer work for us

ALEKS KROTOSKI

Aleks is a social psychologist, broadcaster and journalist. She presents *The Digital Human*.

BBC RADIO 4 92–95 FM & 198 LW

The most overused phrase of the last 18 months has to be 'unprecedented times'. And yes, it was accurate, for a while. But after that while, the times had precedent. Sure, we were still figuring out how to take ourselves off mute, and whether to wear one mask or two in the supermarket, and if shaking hands was okay when greeting someone we'd not seen in the flesh for several months. But we were, in a nutshell, going about our business as usual. It's just that the usual was somehow different. We had arrived in the new normal.

We're remarkably adaptable creatures, and to now try to return to a world as it was before COVID-19 is both disrespectful and impossible. Disrespectful because it's not giving us enough credit for what we can do, and impossible because everything is different now. This isn't coming back to the office after maternity leave and trying to figure out on your own which cupboard you can express milk in without interrupting your colleagues' meetings; we were all in it together. And together, we changed the world.

As author Steven Johnson has written, the best way to guarantee new ideas is to interrupt the routine. A broken treadmill stops us in our tracks; it gives us the opportunity to see what we've become accustomed to for custom's sake, not because there's anything inherently good about what we've been doing. This global interruption allowed us to discard useless and even destructive practices in favour of something that could be better.

"To try to return to a world as it was before COVID-19 is both disrespectful and impossible"

It would be accurate, then, to say that the last few months are unprecedented too. We've had to learn how to use a photocopier again, we've rediscovered the 'delights' of commuting, and frankly we've had to decide if we have the stomach to return to the office. Personally, I can't stand the office. There are too many people wanting to talk about things that distract me from getting more pressing things done. And yet, for the sake of a misplaced nostalgia that ignores the terrible lighting, the recycled air, the eyeballs over your shoulder and the productivity-destroying open-plan setup, many of us have been compelled to return.

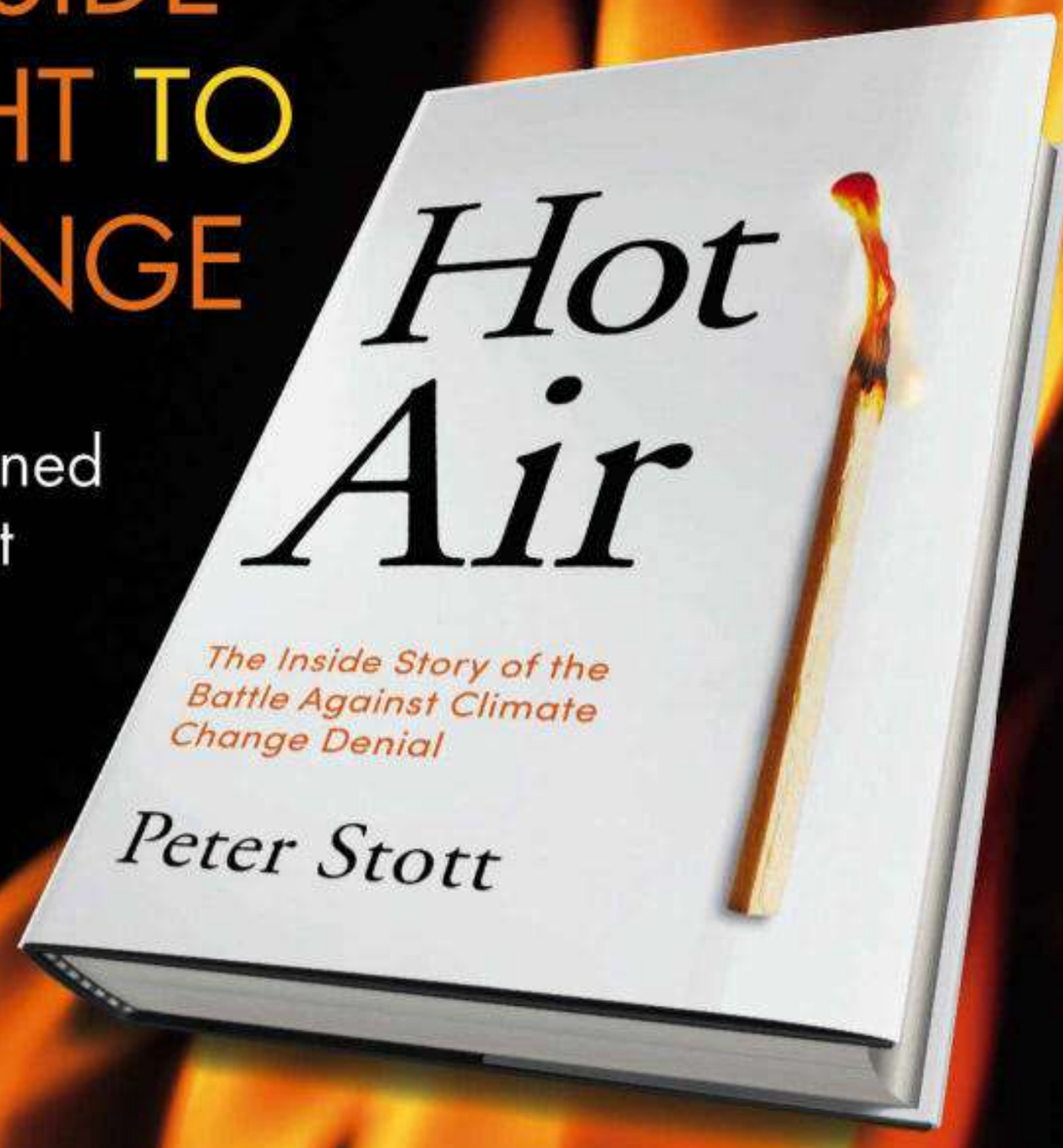
What we found there, amid the husks of deserted snacks left behind in March 2020, was a few moments of novelty and a quick return to a grind that eradicated our autonomy and placed us in the cage again. We don't need to do that. There are a few precious months in which we are feeling our way around again. It's now that we can do something new. Must we have an office Christmas party? Or can we just give the people who want to participate a login to a live-streamed Zoom party?

The pandemic gave us liberty to eradicate our expectations. Think for a moment about why you might be rushing back to the things you did before. Are they really the best you can do? Or do we continue taking the next steps that define our new world, unfettered by the things that came before? Now that would truly be unprecedented. SF

PORTRAIT: KATE COPELAND ILLUSTRATION: SCOTT BALMER

THE SHOCKING INSIDE STORY OF THE FIGHT TO HALT CLIMATE CHANGE

Written by Peter Stott, the world-renowned scientist leading the Science Pavilion at COP26 for the Met Office



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BBC TWO

The new series of *Universe* with Prof Brian Cox starts on 27 October on BBC Two. Check *Radio Times* for details.

IN THE BEGINNING...

Brian Cox's new show, *Universe*, is a scientific creation story. He tells **Sara Rigby** why the series doesn't shy away from the unknown, why he sees the stars as gods, and why he wants to launch Boris Johnson into space.

BBC

WHAT CAN VIEWERS EXPECT FROM YOUR NEW SHOW?

At one level this is a cosmology series. Cosmology forces us to approach the deepest questions because it's ultimately about the origin of the Universe and its fate. Within it, questions are raised about the nature of life in the Universe. How common is life? How did it begin? We're essentially talking about creation stories – so this series is the scientific creation story.

I say right at the beginning that the value of astronomy and cosmology is not so much about the things we discover. It's the fact that it challenges us. So we are forced to accept that we're not the centre of the Universe, that we are a tiny speck in a vast and possibly infinite Universe that may be eternal into the future, possibly even in the past. We don't know. I think the value in such a series is really to say, "This is the arena in which we exist. This is the story of how we came to be here, as told by science," by which I mean the best [explanation] we can do, given our available knowledge.

This series, more than any other that I've done, goes right to the edge of knowledge, in particular, the film about black holes. We're talking about discoveries made in 2020, really fundamental breakthroughs about the nature of space and time and what they are and whether they emerge from a deeper theory.

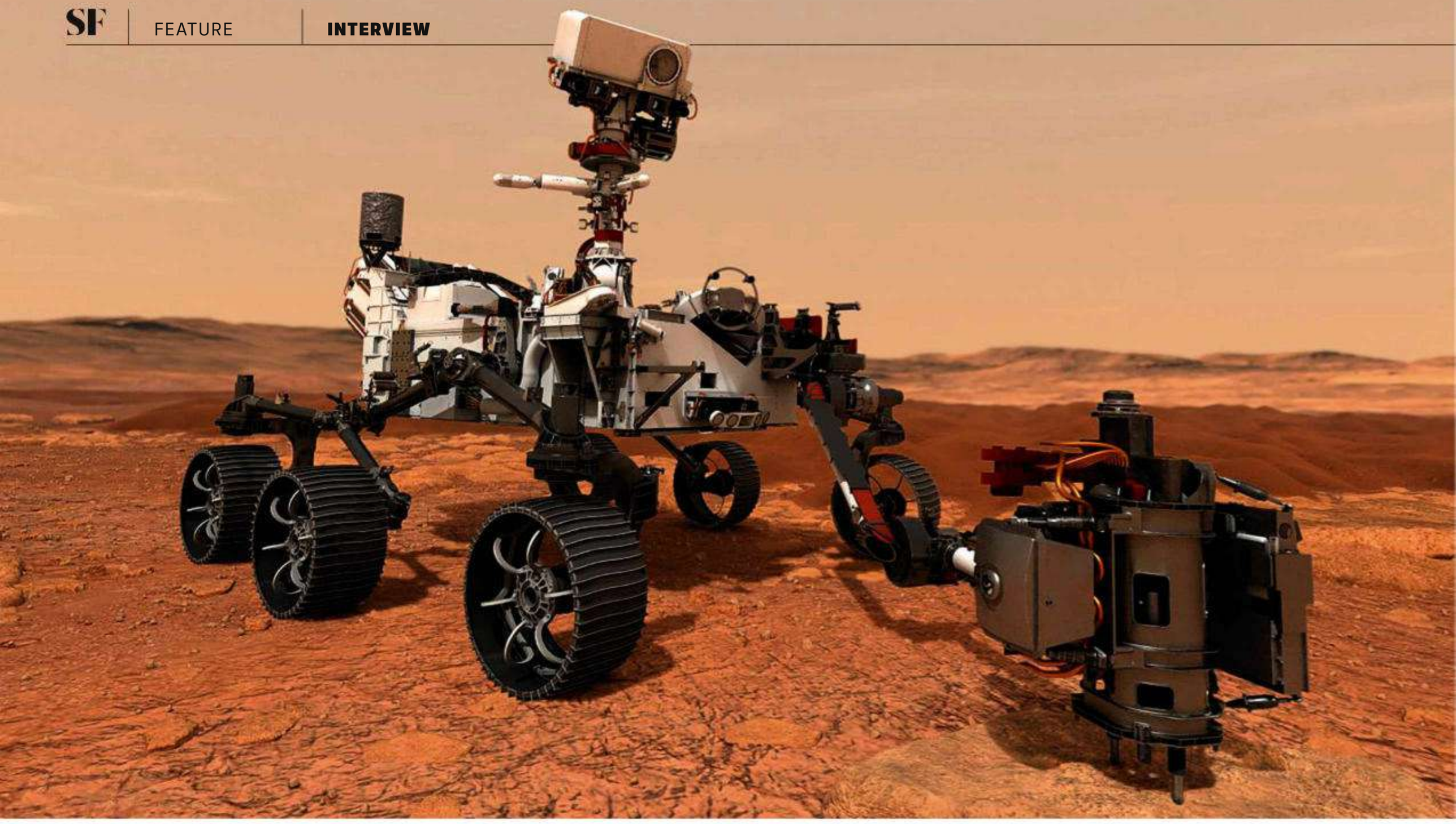
I think the most valuable thing about science is that it forces us to, first of all, recognise what reliable knowledge is. And secondly, it forces us to understand where the horizon is, where the edge of knowledge lies. And it rests on the fact that we're prepared to peer over the horizon into the darkness without fear. We don't shy away from it. We say, well, this is exciting. There's stuff we don't know. The stuff we don't know now is fairly profound and fundamental. And that's ultimately what the series is about.

IN THE FIRST EPISODE, YOU TALK ABOUT STARS AND HOW THEY BRING MEANING TO THE UNIVERSE. COULD YOU TELL US A BIT ABOUT THAT?

I've made loads of films about stars. Lots of people have made films about stars. And so we thought, what does the story of the stars really tell us? There was a time before stars, and though we don't know where it was or what it was like, there was a first star... and there will be a last star. We know this because the Universe is accelerating in its expansion and the age of stars is finite. New stars are not made at the same rate, old stars die, and so there'll be a last star. And so we thought, that's an interesting story. We'll tell the story of the stars from the first star to the last star.

And also, in order to have a living Universe, you need the stars. It's well known that the stars make the heavy elements out of which we're made. It's also perhaps less well known that the way those elements can be assembled into complex structures is reliant on the stars, is reliant on hot spots in a cold sky. The science of thermodynamics says that you can't do anything without temperature differences. So we, in a sense, live in a giant steam engine powered by the Sun. That's the physics of what's happening here on Earth.

And so in that sense, by any definition that I can find of the word 'god', the stars qualify, because they're creators, they create the building blocks of life. They're the foundation of virtually all life on Earth today, apart from some rather exotic bacteria deep underground. The foundation of it ➔



all is photosynthesis, which is an interface between the stars and the cold of space, basically, it's an engine. And so quite provocatively, but I think logically, the stars are gods.

But what we find interesting is that stars are mortal. They were born and they will die. And I thought that was an interesting way to talk about what these things are. There's a strong element in the series of challenging the audience to think, and so it's not just a presentation of facts. Given what we know, what are we to make of this knowledge? That's basically the foundation of the series. It's an intellectual challenge.

IF YOU COULD SELECT WHERE THE NEXT BIG SPACE MISSION WOULD GO, WHERE WOULD YOU CHOOSE?

Oh, there are two answers. In Solar System exploration, to me, the search for life beyond Earth is really important. So Europa, where the Europa Clipper mission is now, is absolutely fascinating and valuable. You could also argue that another mission to Enceladus would be extremely valuable. The Sample Return Missions from Mars are really important, because they're exobiology missions [that look for life beyond Earth].

Beyond the Solar System, I think that gravitational wave astronomy is absolutely fundamental, a completely new way of observing the Universe. For the first time really in the history of astronomy, we've got something other than light [to observe the Universe]. I'd like to see a big gravitational wave detector in space.

The continued high-precision measurements of the cosmic microwave background are also really important, because that's our window onto the very early Universe. It is also our window onto our theories about what happened before the Big Bang. There are very specific predictions about structures in the cosmic microwave background that we need to test, and we're not quite sensitive enough to test them yet.

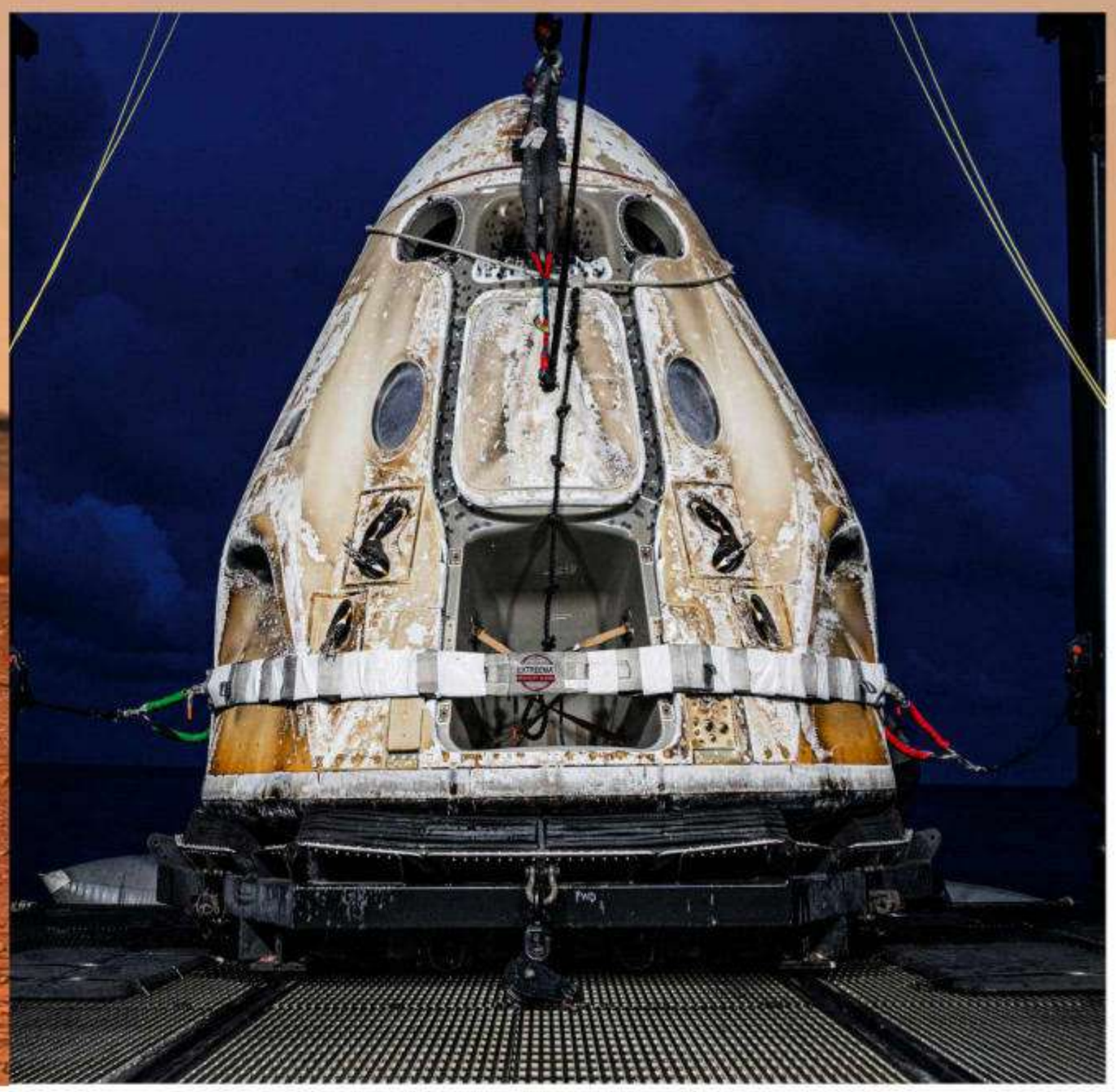
SPACEFLIGHT IS CHANGING AND BECOMING MORE COMMERCIAL. WHAT DO YOU THINK ABOUT THIS?

I think it's great. The history of aviation, and

"I would make it compulsory for anyone who wants to run a country. I would launch Boris Johnson, Joe Biden... I'd launch them into space"

ABOVE The Mars Sample Return mission will bring rocks and soil from the Red Planet back to Earth

NASA/JPL, SPACEX/FLICKR



the history of almost anything, tells us that in the early days it tends to be funded by governments. But ultimately, if you're going to make spaceflight routine, it has to be in the private sector, it can't be government-controlled. It needs to be cheap, and it needs to work reliably. If we are going to make it work, it needs to be like aviation is today. I think we are there, pretty much.

It's astonishing to me that after a long time of being quite miserable following the Apollo programme and seeing very little progress – other than the International Space Station, which is a tremendous achievement – we've just seen the first entirely commercial non-professional crew go into space for three days and come back again. While that will be characterised as, you know, a rich person's plaything or a stunt, to me, what it represents is the fact that spaceflight is becoming routine.

And that's really important, because if you think about it, if you strip away all the emotional baggage from it, we've already industrialised Earth's orbit. This is vital, because answers to fundamental questions are coming from satellite observations. Like our understanding of the climate, measurements of ocean surface temperatures, land use patterns, weather forecasting, communications and so on. We wouldn't have access to this information otherwise. It's already vital to the infrastructure of our civilisation.

ABOVE The SpaceX Inspiration4 mission was the first human spaceflight to orbit Earth with only private citizens on board. The Crew Dragon returned to Earth on 18 September and was picked up by a recovery ship

PROF BRIAN COX
Brian is a particle physicist and the Royal Society Professor of Public Engagement in Science. He worked at the Large Hadron Collider at CERN, before appearing in a number of BBC radio and television programmes. He has presented Horizon, Wonders Of Life *and* Wonders Of The Universe, *and co-presents* The Infinite Monkey Cage *on BBC Radio 4 with Robin Ince.*

And so the fact that we are beginning to be able to get into space cheaply, reliably and safely means that it is going to expand. To me, that is entirely a good thing. The fact that it's now been essentially dominated by the private sector is also a good thing, because it means that it's not taxpayers and governments that are doing it an extremely expensive way. It's the commercial sector.

WOULD YOU BOOK A FLIGHT INTO SPACE, IF YOU COULD?

I'd love to see the Earth from space. And I think that's going to be one of the valuable spinoffs, actually, of this new space race. And I've really been privileged to meet a lot of astronauts from the Apollo times, and even the Mercury programme. In those days, they were all test pilots and not given to overly emotional responses to things. But what they all shared was a profound feeling of the fragility and value of our planet. It sounds a bit happy-clappy to say that, but it's not, because they do.

I think, almost without exception, they were all profoundly moved by it. When looking back at the Earth, one of the Apollo astronauts said that line that's delivered in *Mars Attacks!*: "Why can't we all just get along?"

I do think that the more people experience that, the more we will come to value our planet and our fellow human beings and our civilisation. I think that's demonstrably true, given the nature of the reaction of the astronauts that have seen it.

So I would make it compulsory for anyone who wants to run a country. I would launch Boris Johnson, Joe Biden… I'd launch them into space. I think they should go. The cheapest one is Virgin Galactic, what is it, about $400,000 or $500,000 dollars? That would be a good investment.

Go up there, look at the planet that you are responsible for, look at it in the cosmic context, the context in which it sits and then come back and make your choices. And I would gladly pay my tax to send Boris Johnson into space… and return him safely to Earth. SF

Since just after the Big Bang, ancient black holes may have been shaping the Universe as we know it. Now, scientists are tantalisingly close to glimpsing these mysterious objects for the first time

by **COLIN STUART**

Out there among the stars lies a hidden swarm of black holes. They have been around ever since the dawn of time, quietly and not so subtly influencing the evolution of the Universe. Without them there would be no stars, no planets and no life to marvel at the Universe's wonders. Now, for the very first time, we may finally have the tools to find them.

Black holes are one of astronomy's most famous objects. Their gravity is so extreme that escape is impossible if you venture too close. There are different sizes of black holes, but they are normally gargantuan ➲

ABOVE
Gravitational wave detectors such as VIRGO could help us find signals from primordial black holes

monsters considerably more massive than our own Sun. They usually remain hidden from view because no light can escape to reveal them to us. Yet we have seen them, thanks to gravitational wave detectors like LIGO and VIRGO that have detected signals from colliding black holes. We've never been more confident that these cosmic trapdoors exist.

However, there is one type of black hole that still remains theoretical, one that could solve a long-standing cosmological conundrum to boot.

Immediately after the Big Bang there were small fluctuations in the new Universe's density – regions that had slightly more or less mass than the average. Where the mass was above the norm, material could have collapsed to form mini black holes. As they've been around for pretty much as long as the Universe itself, these black holes are called 'primordial' black holes.

According to theoretical models, primordial black holes can have a wide range of masses. They could be lighter than an eyelash or heavier than a star. So far we've been able to rule out some masses through observations, opening up two possible mass ranges or 'windows' for primordial black holes.

"The two windows are less than one lunar mass [one lunar mass = mass of our Moon] and a few tens of solar masses [one solar mass = mass of our Sun]," says Prof Sohrab Rahvar, an astrophysicist and cosmologist from Sharif University of Technology in Iran.

If this hidden population of miniature black holes exists, then they could account for some or all of the dark matter – the invisible glue that astronomers think helps hold galaxies like our own Milky Way together. It's an idea that fell out of favour, but is now gaining traction again – particularly as traditional notions of what dark matter is made of continue to draw a blank.

SMALL BUT MIGHTY

With one eye on dark matter's true identity, PhD student Gabriele Franciolini, from the University of Geneva, Switzerland, has been re-modelling the production of primordial black holes after the Big Bang in more detail. The upshot? "There could be hundreds of times more primordial black holes out there," he says. "You can explain all of the dark matter through primordial black holes." That's if they have a mass in the lower

GETTY IMAGES X2, NASA, SCIENCE PHOTO LIBRARY, ESA

“YOU CAN EXPLAIN ALL OF THE DARK MATTER THROUGH PRIMORDIAL BLACK HOLES”

window, below that of the Moon, which would make them less than one-tenth of a millimetre in diameter – about the width of a human hair.

In this case, each primordial black hole would be tiny, but together they could provide enough gravity to keep a galaxy from flying apart. If galaxies like our Milky Way are chock full of teeny adhesive black holes then they should be everywhere. Amir Siraj, a theoretical astrophysicist from Harvard University, believes there’s even a chance that one is lurking in the outskirts of our Solar System.

THE FOUR TYPES OF BLACK HOLE

PRIMORDIAL
(A RANGE OF DIFFERENT MASSES)

These are as-yet-unconfirmed relics from the formation of the Universe in the Big Bang. So far we’ve been able to rule out their existence in certain mass ranges, but the door is still open to the possibility that the Universe is littered with tiny black holes. Together, they could explain the dark matter mystery – the fact that there appears to be an invisible glue binding galaxies together.

STELLAR MASS
(5 TO 100 SOLAR MASSES)

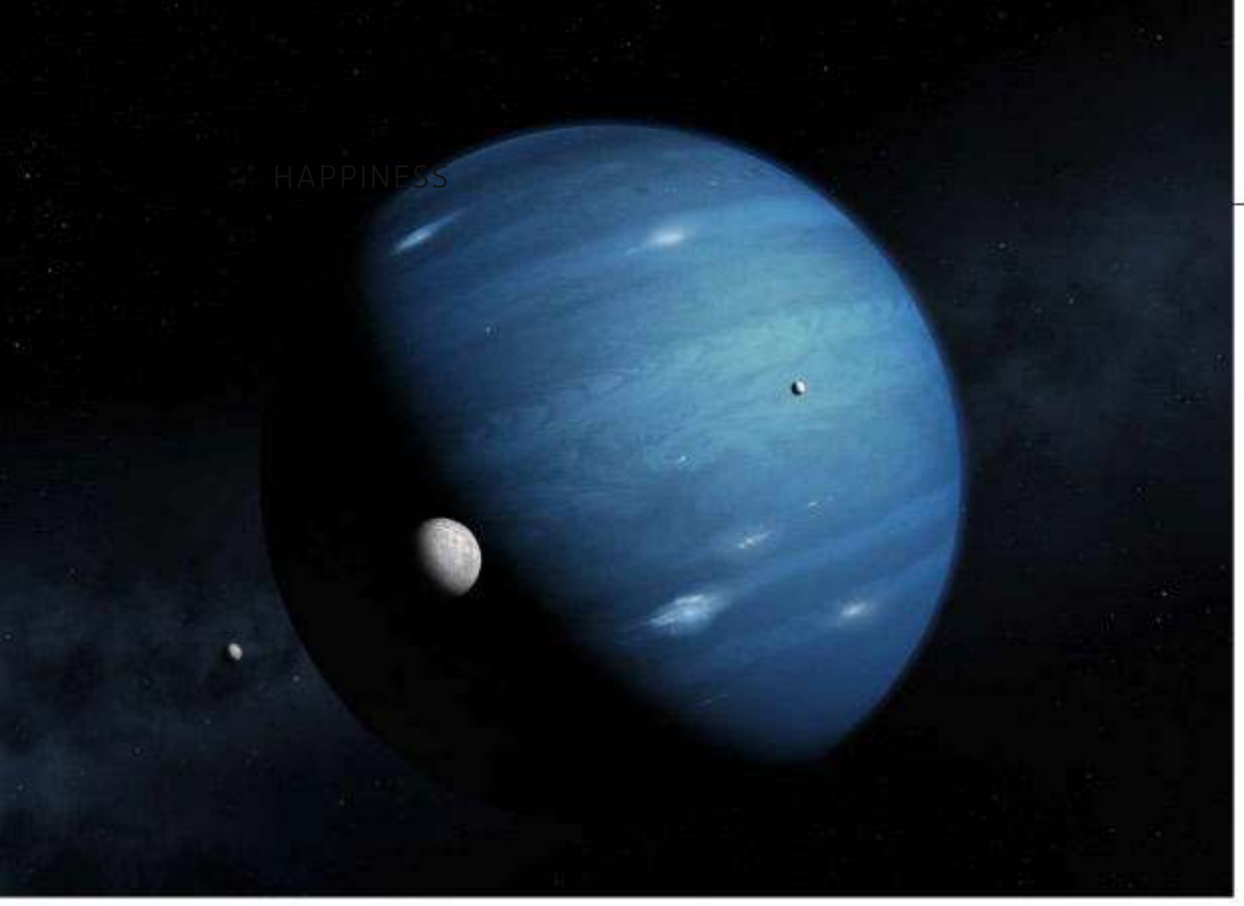
These are your so-called ‘ordinary’ black holes. When the most massive stars die – those more than 30 times the mass of the Sun – they explode into a supernova. The star’s core collapses into an infinitely small, dense point called a singularity. The gravity is so strong that anything venturing within a certain distance of the singularity – a region called the event horizon – cannot escape its clutches.

INTERMEDIATE
(100 TO 1,000,000 SOLAR MASSES)

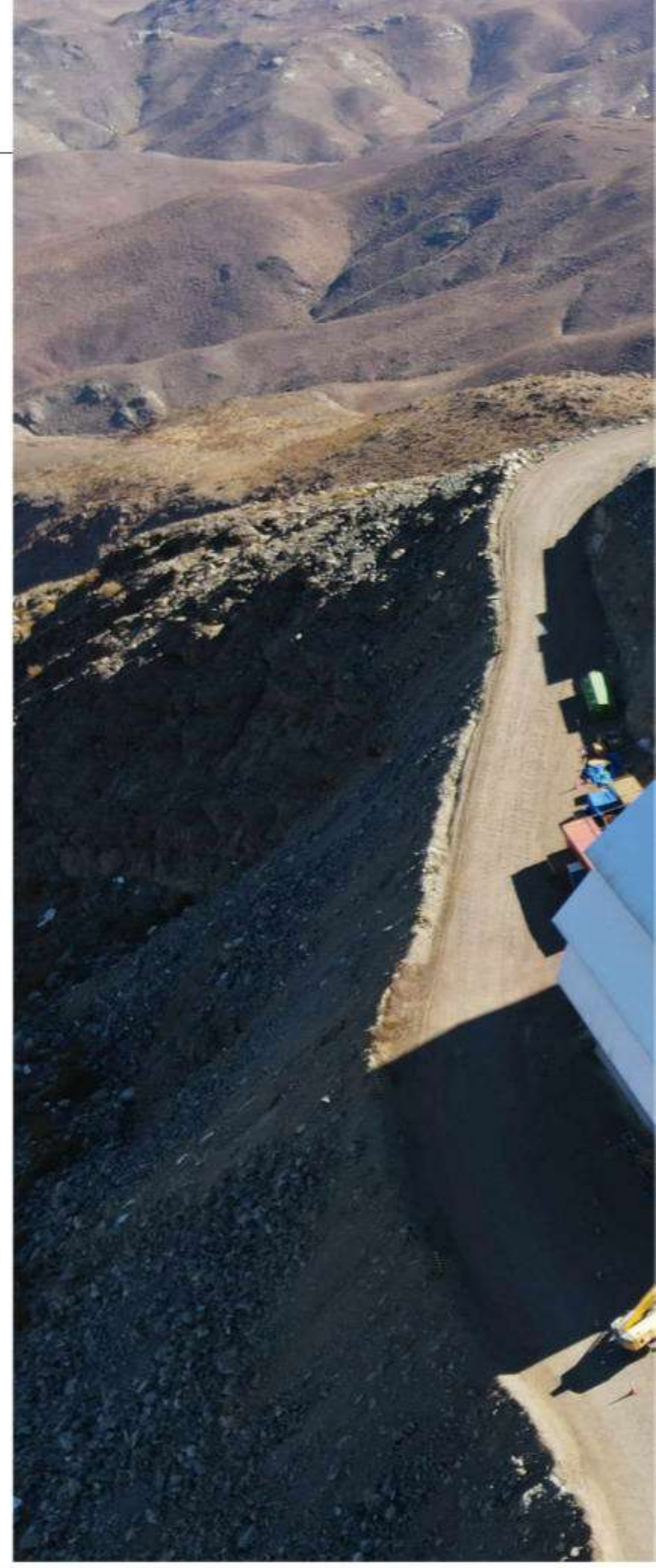
For decades, astronomers puzzled over the fact that there are stellar mass black holes and supermassive ones, but seemingly very little in the middle. This was odd because big black holes are thought to be constructed through mergers of smaller ones. There was a missing link in this construction chain. But in March 2020 a 50,000 solar mass black hole may have been spotted by the Hubble Space Telescope.

SUPERMASSIVE
(GREATER THAN 1,000,000 SOLAR MASSES)

These leviathans are found in centres of major galaxies and are the seeds around which the galaxies are constructed. The one at the heart of our own Milky Way is called Sagittarius A* (pronounced ‘A star’) and tips the scales at around four million times the mass of the Sun. That pales in comparison to the supermassive black hole in the galaxy M87, which weighs in at a whopping seven billion solar masses.



LEFT It has been proposed that a ninth planet is shepherding small objects beyond Pluto, but some experts propose the planet could actually be a black hole



ABOVE The Vera Rubin Observatory becomes fully operational in 2023 and should be able to detect signs of a primordial black hole in the outer reaches of our Solar System

RIGHT A black hole is a region of space-time in which gravity is so powerful that not even light can escape

For a decade or so, astronomers have been puzzled by the orbits of small objects beyond Pluto. Their paths around the Sun should be pretty random, but they appear organised. It's as if something is shepherding them onto similar trajectories. But what? "It's most likely a planet," says Siraj. Dubbed Planet Nine, it would be the first newly discovered planet since Neptune was added to the register in 1846 (Pluto was called a planet upon discovery in 1930, but later demoted to dwarf planet status in 2006). However, extensive ongoing searches have failed to find any visible sign of such a world. "If direct searches continue to fail, then a primordial black hole becomes an option," Siraj says. After all, as Arthur Conan Doyle's fictional detective Sherlock Holmes famously said, once you eliminate the impossible, whatever remains, no matter how improbable, must be the truth.

We know how much gravity we need to account for the clustered orbits of the objects beyond Pluto. If that gravity *is* being provided by a primordial black hole, then it is merely the diameter of a grapefruit. Yet despite its small size, it would still be approximately 10 times heavier than the Earth. If this is really what's going on then it's no surprise that telescopic trawls of the outer Solar System have so far come up empty.

Siraj thinks there is a way we could see it, though. It's an idea that came to him during the first COVID lockdown while he was staying in his childhood bedroom at his parents' house.

"The black hole should produce the occasional accretion flare," he explains. In other words, we should see a flash if the grapefruit-sized object gobbles up a passing comet. Such an event would release a few per cent of the energy of the atomic bombs dropped on Japan at the end of WWII.

The flash may be intense, but it is happening a long way away in the backwaters of the Solar System. That makes the light pretty faint by the time it reaches Earth. Still, there is a new telescope about to come online that should be up to the job. "The flares are right on the detection limit for the Vera Rubin Observatory," Siraj says. "It's the perfect tool for ruling out a primordial black hole in the outer Solar System." The observatory should start proper observations towards the end of 2023.

Should a primordial black hole turn out to be there, it likely entered the Solar System due to the fact that the Sun is dragging us through the minefield of the Milky Way as it orbits around the galactic centre. For some reason this one got stuck, but could a primordial black hole go further and enter the inner Solar System? Rahvar certainly thinks so. He's calculated the chances of a primordial black hole passing through the Earth during our planet's 4.54-billion-year history. "The probability is one passage per billion years," he says. If he's right, we've been struck by a primordial black hole on four separate occasions.

"EARTH GETTING HIT BY A BLACK HOLE SOUNDS APOCALYPTIC, BUT IT ISN'T NECESSARILY. WE'RE STILL HERE, AFTER ALL"

Rahvar's calculation assumes 100 per cent of dark matter is made of sub-lunar mass primordial black holes. Even if they make up just a quarter of dark matter, Earth has still encountered a primordial black hole once before and is likely to do so again.

HELLO, DARKNESS

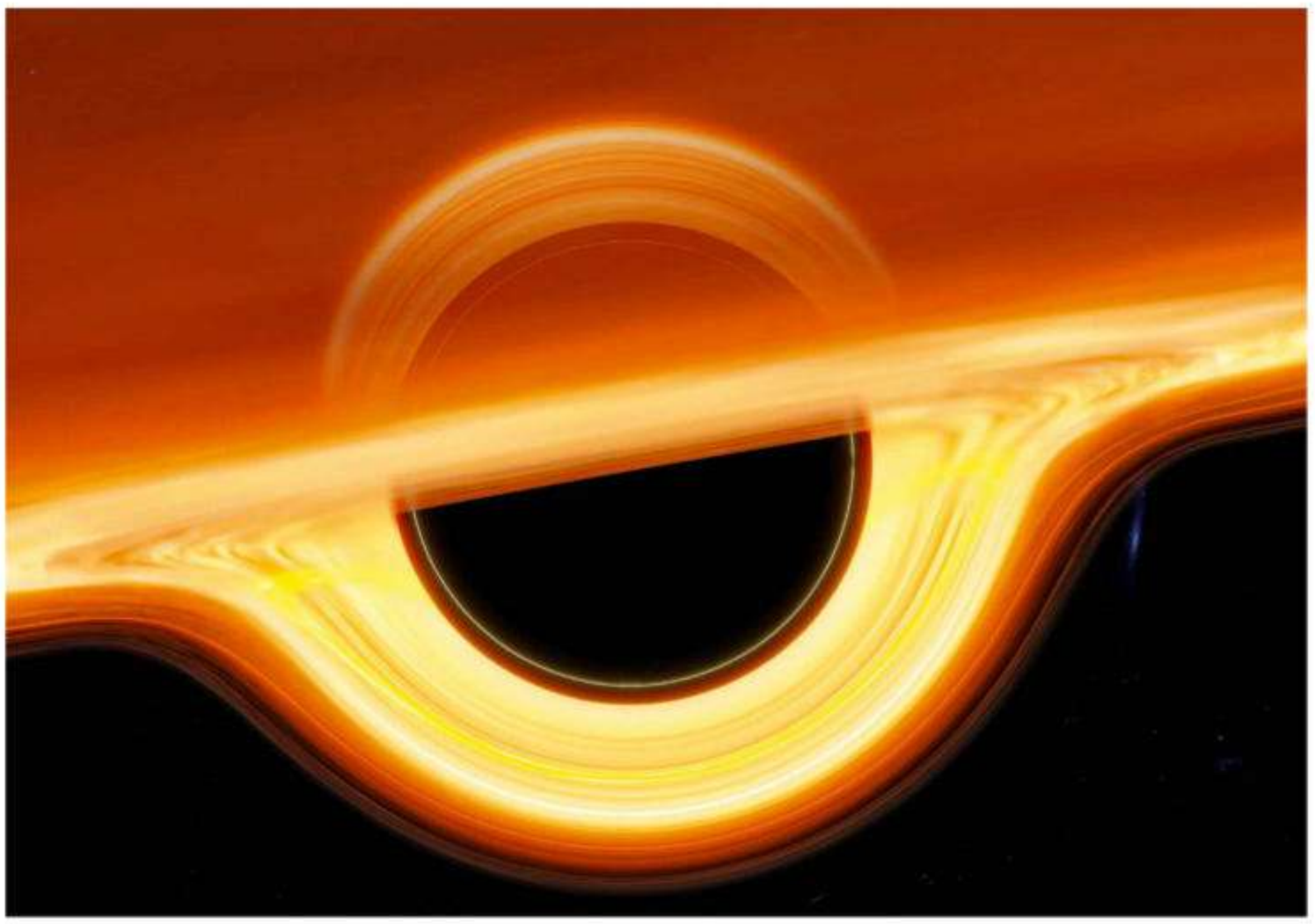
Our planet getting hit by a black hole sounds apocalyptic, but it isn't necessarily. We're still here, after all. The worst outcome is that the primordial black hole settles in the Earth's core. "Then the black hole starts to swallow all the matter of the Earth, grows and after a finite time the Earth will collapse into the black hole," Rahvar explains.

Fortunately, Rahvar's calculations reveal that the probability of trapping a black hole inside the Earth is almost zero. What is far more likely is that the black hole passes straight through the planet and emerges on the other side to continue its journey through space. If it happens to pass through you, however, the results aren't pretty (see box, overleaf).

How can we tell if a black hole really has passed through the planet? "During its passage through the Earth it can heat the planet's interior," says Rahvar. This could show up as melting traces in rocks along the straight line that represents the black hole's path. However, Rahvar cautions that as this has only occurred a maximum of four times in Earth's entire history, it would be extremely difficult to discover these traces.

So how else could we prove that primordial black holes really exist? Franciolini thinks that the answer is the same way we proved that ordinary black holes exist: gravitational waves. Observed for the first time in 2015, gravitational waves are ripples in the fabric of the Universe itself, caused by events happening within it. The gravitational waves that we've detected so far have come from collisions between compact objects like ordinary black holes and neutron stars. Or at least that's the conventional wisdom. Franciolini isn't quite so sure. "A significant fraction of the events could be of primordial origin," he says.

Now we're talking about primordial black holes in the upper mass window – those weighing in at tens of solar masses. We know from an effect called 'gravitational lensing' that primordial black holes in this mass range cannot make up more than 10 per cent of dark matter. Gravitational lensing is where a foreground object (say a black hole) magnifies the light of a background object (like a star). If there ➤



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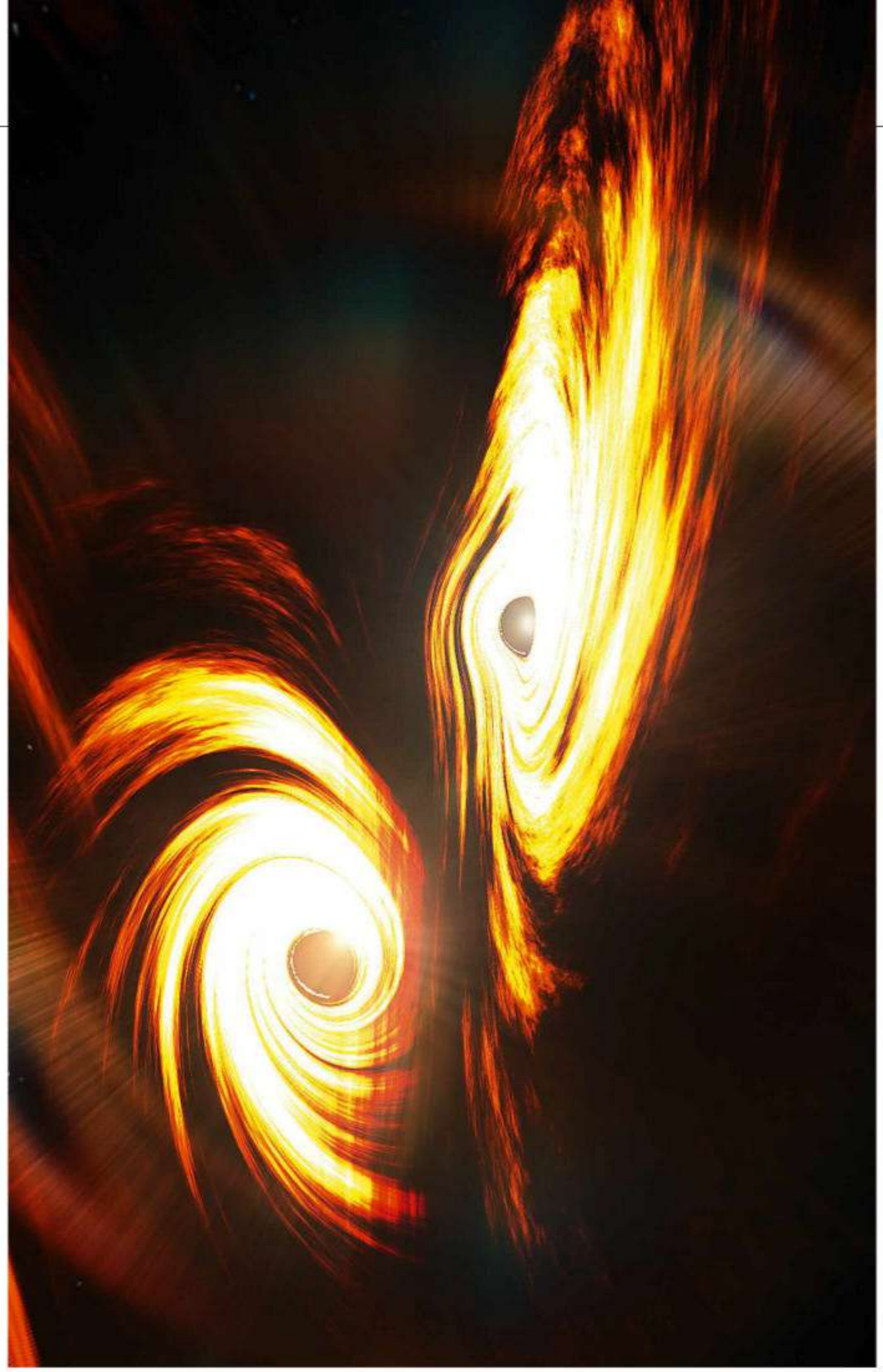
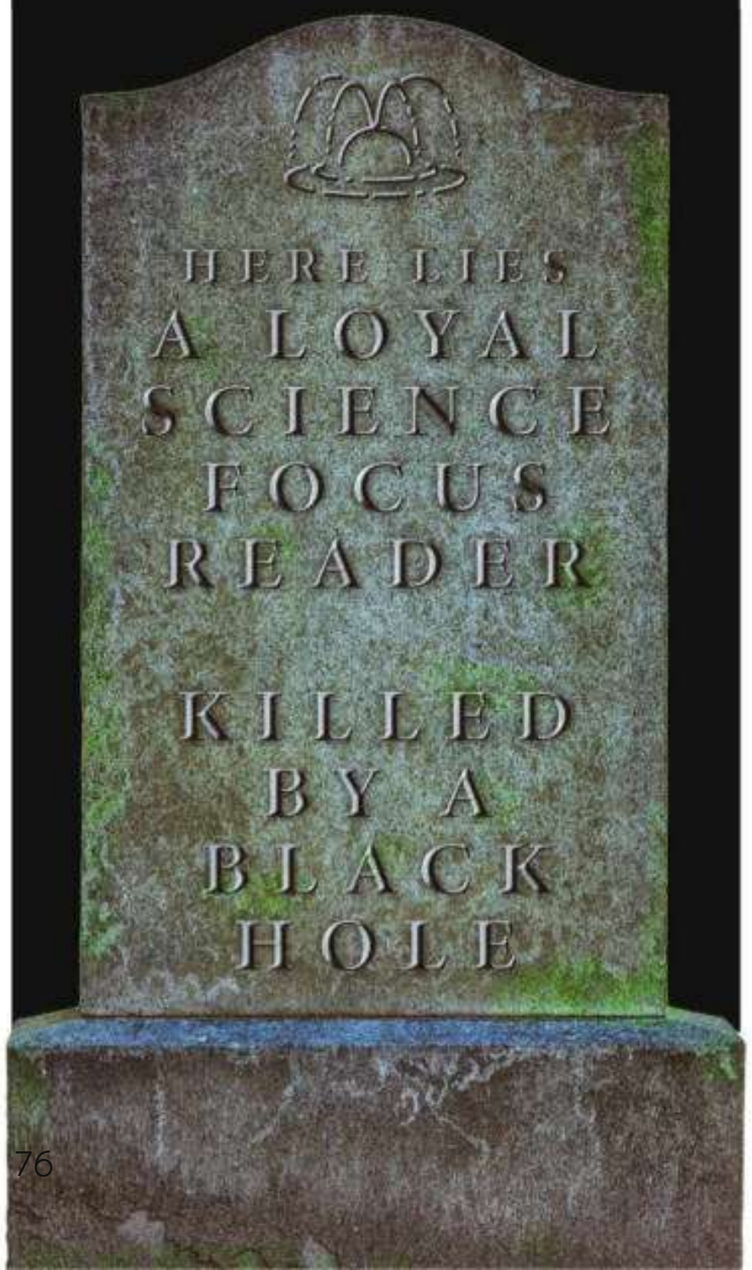


WHAT IF...

WHAT WOULD HAPPEN IF YOU WERE HIT BY A PRIMORDIAL BLACK HOLE?

Well, first off, you'd probably be the unluckiest person in human history. According to Prof Sohrab Rahvar, an astrophysicist and cosmologist from Sharif University of Technology in Iran, Earth has only been hit by a maximum of four primordial black holes in its entire 4.54-billion-year existence. For one to pass through the Earth during your lifetime is almost impossible. For it to pass through the narrow one-metre corridor that coincides with where you are is off-the-scale unlikely.

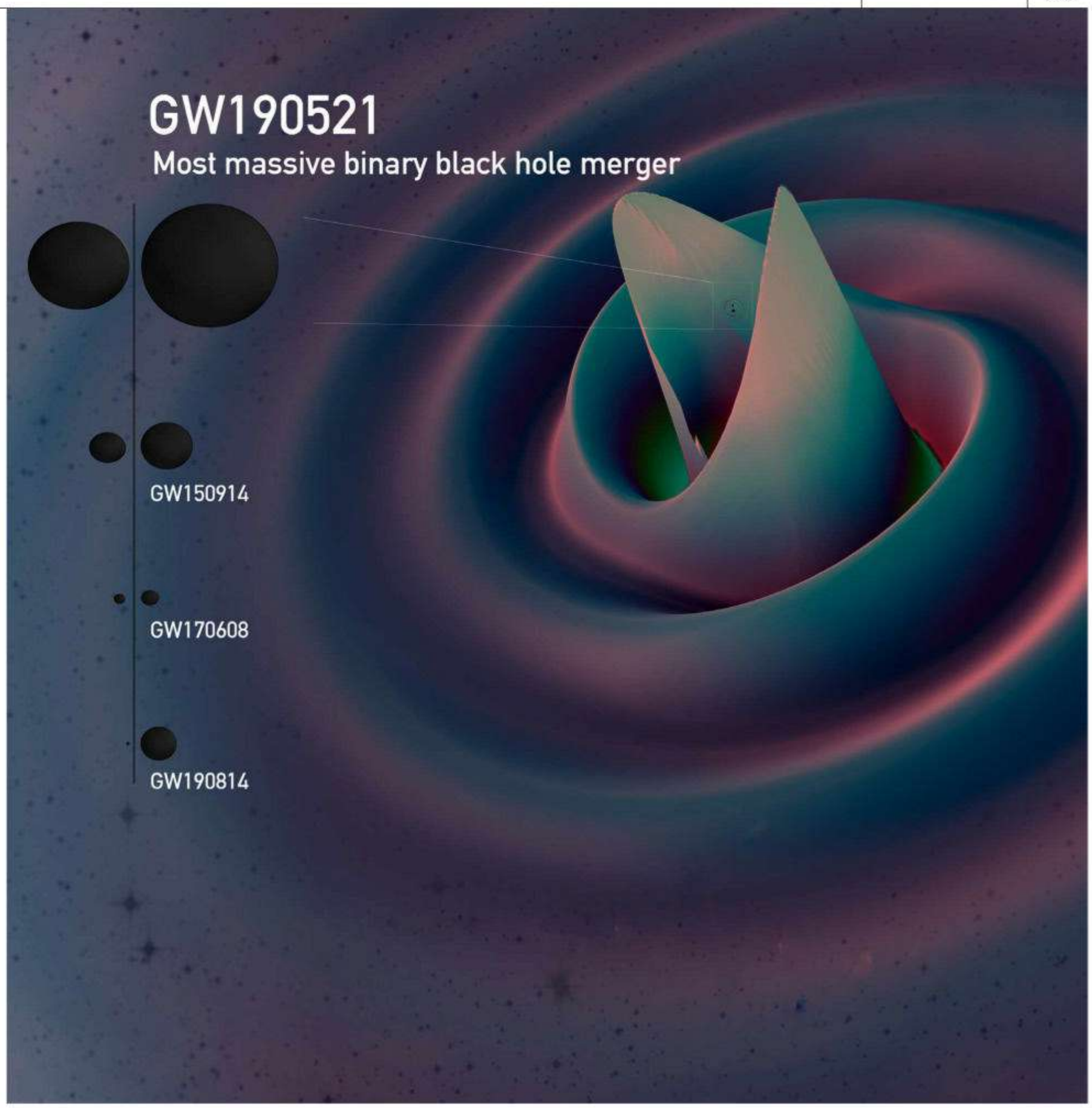
That said, you're in for a torrid time should you be fortune's fool. The primordial black hole will only be in your body for 10 microseconds, but will be travelling at 160km/s (0.05 per cent of the speed of light). Although the black hole is only 1,000 times wider than an atom, it comes with its famous brand of intense gravity. According to Prof Avi Loeb, the esteemed theoretical physicist from Harvard University, it's enough to shrink your body by a couple of inches. All of your internal organs will become distorted as the black hole warps the very fabric of space in which they reside. It would lead to an agonising death. Still, imagine the epitaph – 'Here lies – [insert your name] – killed by a black hole'.



"THE DATA SUPPORTS THE IDEA THAT PRIMORDIAL BLACK HOLES ARE THERE, BUT WE NEED MORE DATA AND MORE WORK ON THE THEORY SIDE"

were lots of big primordial black holes around then we'd see more of these events than we do – hence the 10 per cent ceiling.

According to Franciolini, if large primordial black holes represent just 0.1 per cent of dark matter then they would merge with each other at the same rate as ordinary black holes do. If we've been able to see the latter, there's a good chance we've also already seen the former. In other words, we've already spotted two large primordial black holes colliding and wrongly assumed it was two ordinary black holes instead. "You have to disentangle the two scenarios," says Franciolini. "That's the challenge."



LEFT Artist's impression of the two colliding black holes that were detected in 2019

RIGHT The event was named GW190521. In this graphic, the ripples illustrate the gravitational waves produced by the two black holes

GETTY IMAGES, MARK MYERS/ARC/OZGRAV, NSF/LIGO/VIRGO

One recent gravitational wave event is particularly intriguing: GW190521. It takes its name from the fact that it was detected on 21 May 2019, and the discovery was subsequently announced in September 2020. This particular merger of two black holes produced a single black hole that tips the scales at 140 solar masses. That's big enough to class it as an intermediate black hole. According to Franciolini, it's harder to explain the existence of such a monster merger with ordinary black holes. That opens the door to the possibility of a primordial origin instead. "The data supports the idea that primordial black holes are there," Franciolini says, "but we need more data and more work on the theoretical side."

We might not have to wait too long for that deluge of data, as we're already building out our network of gravitational wave detectors. The Kamioka Gravitational Wave Detector (KAGRA) in Japan will soon join forces with LIGO and VIRGO after some setbacks due to the COVID pandemic and Hurricane Ida. Plans are underway for a new LIGO detector in India later this decade. With four detectors spread around the globe, astronomers will be able to pinpoint gravitational wave events across the entire sky. Right now they are limited to just half of the heavens.

The new gravitational wave detectors should bring more black hole mergers events with more precise data. Researchers like Franciolini are eager to comb through that data for any signs of primordial black holes. Perhaps then we'll know whether these ancient, invisible relics have been silently steering the evolution of the Universe, binding galaxies together and setting the stage for us to build gravitational wave detectors in the first place. **SF**

by **COLIN STUART** *(@skyponderer)*

Colin is an astronomy author and speaker. Get a free ebook at ***colinstuart.net/ebook***

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Q&A

YOUR QUESTIONS ANSWERED

... DOES SITTING BY A WINDOW HELP YOU WORK BETTER?
... COULD WE HARNESS ENERGY FROM A BLACK HOLE?
... CAN ANY ANIMALS PHOTOSYNTHESISE?
... WHY DO OUR VEINS LOOK BLUE?
... WHY IS SKIN SO RUBBISH?
... HOW MANY BIRDS ARE KILLED BY WIND TURBINES?
... HOW LONG DID DINOSAUR EGGS TAKE TO HATCH?
... I WORK IN CUSTOMER SERVICES. WHY IS BEING POLITE ALL THE TIME SO EXHAUSTING?
... WHAT WOULD HAPPEN IF ALL THE VOLCANOES ON EARTH ERUPTED AT ONCE?
... WHAT'S THE DIFFERENCE BETWEEN A MIGRAINE AND A HEADACHE?

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LUIS VILLAZON
Science and technology writer

ILLUSTRATION: DANIEL BRIGHT

ARLO HEAD, LONDON

WHAT ANIMALS COULD MOST HUMANS BEAT IN A FIGHT?

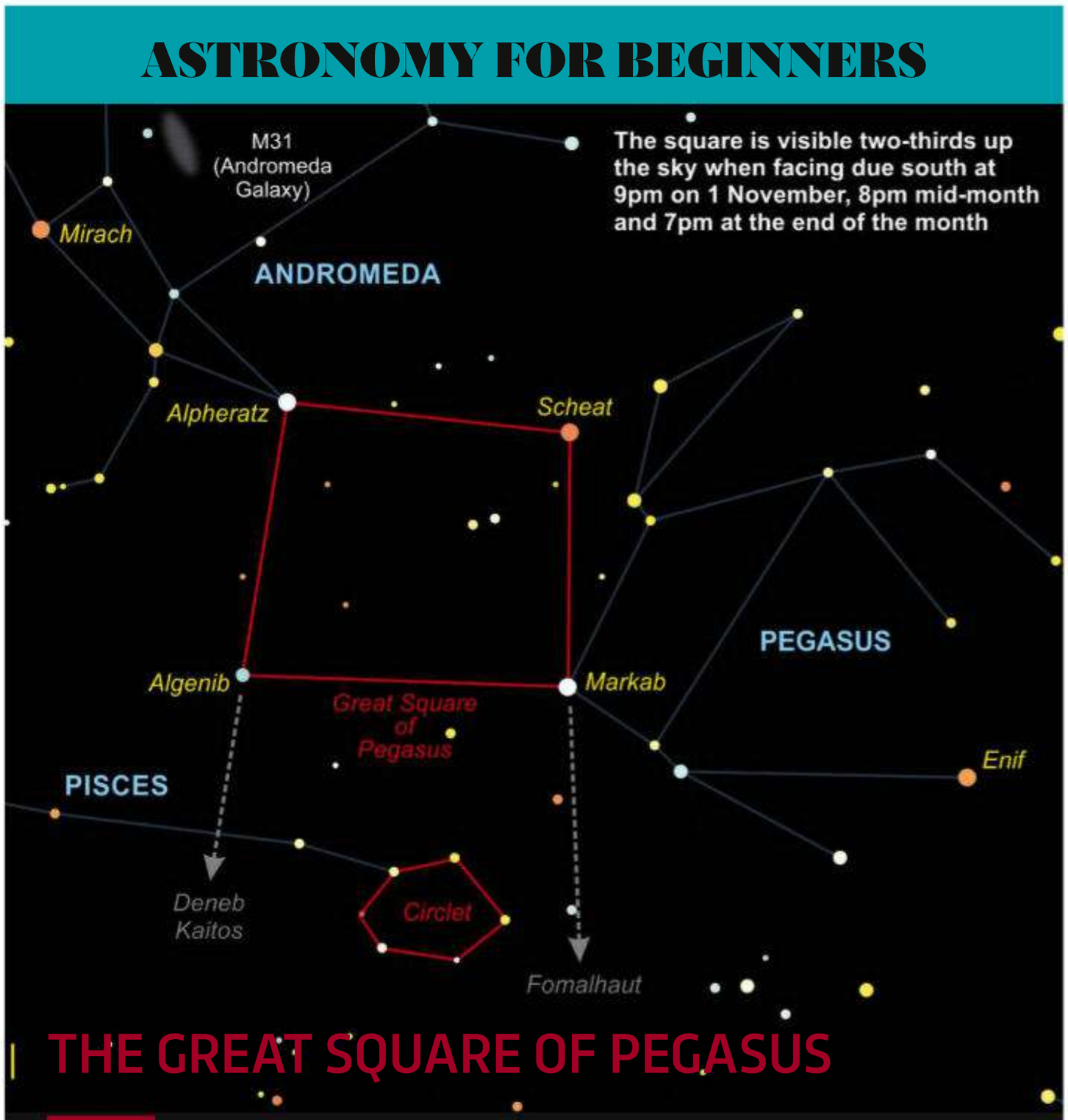
According to a recent YouGov poll that asked which animals British people thought they could beat in unarmed combat, 38 per cent thought they could 'ruff' up a medium-sized dog, 18 per cent thought they could vanquish an eagle, and 7 per cent fancied their chances against the world's longest venomous snake, the king cobra. Rats and house cats were the easiest presumed pushovers, with two-thirds of participants claiming they could see one off, while grizzly bears, elephants and lions were rightfully respected – only 2 per cent of pollsters claimed they would be able to take one down.

Perhaps unsurprisingly, British men were more likely than British women to think they could win a fight with an animal. For example, 15 per cent of men felt they could take on a chimpanzee, compared with just 4 per cent of women.

Across the Atlantic, Americans were more brazen, believing they could bag a win. Inexplicably, the effect is greatest for geese, with 61 per cent of people in the US claiming the ability to subdue an angry goose, compared with 45 per cent of Brits.

Thankfully, no animals were harmed in the making of this poll. It's all opinion, bluster and hubris. ***HP***

ASTRONOMY FOR BEGINNERS



THE GREAT SQUARE OF PEGASUS

WHEN: AUTUMN

The Great Square of Pegasus is prominent during autumn, and although charts suggest a large, dominant shape, the reality is a little different. The square's corners are marked by middle-brightness stars easily seen under most sky conditions. None of the sides are exactly the same length, on average appearing similar to the distance between your index and little finger when outstretched at arm's length.

Technically, the Great Square is an asterism, an unofficial pattern. Its upper-left corner (when viewed from the UK) is marked by Alpheratz, the primary star of Andromeda, the remaining corners belonging to Pegasus. The shape represents the upside-down torso of Pegasus the Flying Horse.

Although the Great Square may look empty, faint stars do appear within it and the number seen is a good indication of sky quality. A heavily light-polluted sky will show none. Up to five is average, with up to 13 really good. Under exceptional circumstances, 35 stars can be counted within the square with the naked eye.

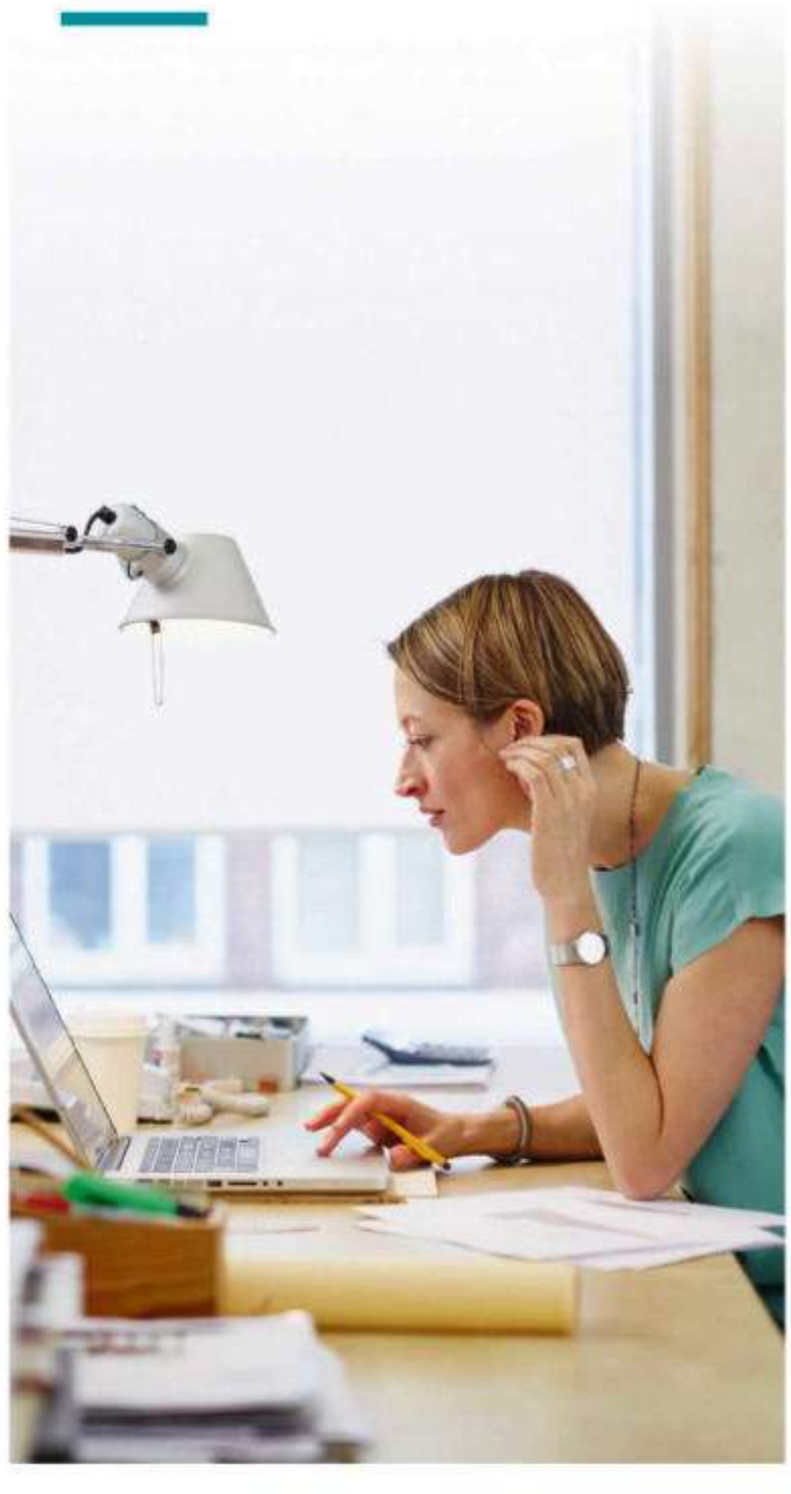
If your skies are dark, once you've identified the Great Square, look a square-side length below it to locate a faint circle of stars. This is the Circlet, another asterism representing one of the fish in Pisces the Fishes.

When the Great Square lies high in the south, follow its right side down towards the horizon to locate Fomalhaut, the brightest star in Piscis Austrinus, the Southern Fish. The left side of the square points down to Deneb Kaitos, the brightest star in Cetus the Whale.

Finally, if you have clear skies on the morning of 19 November, Earth's shadow creeps across the face of the Moon from 7:18am, the start of a partial lunar eclipse. This event favours those living in the north and west of the UK, the Moon setting soon after the eclipse starts for most of the country. ***PL***

NEIL SLATER, FALMOUTH

DOES SITTING BY A WINDOW HELP YOU WORK BETTER?



Yes. A 2018 study at Cornell University found that natural light from a window reduced eye strain, headaches and drowsiness. And a 2021 study at the Bartlett School of Architecture, University College London, found that workers in open-plan offices were most productive when sat at window desks. However, this depends on the office layout. Workers facing windows with a large number of desks behind them reported lower productivity. Possibly due to the nagging fear of co-workers talking about them! ***LV***

NAOMI SHEEN, HULL

COULD WE HARNESS ENERGY FROM A BLACK HOLE?

Scientists have long considered whether energy can be extracted from black holes. One possibility, called the 'Penrose process', makes use of the 'ergosphere' – the volume just above a rotating black hole's event horizon where space-time itself is dragged along with the stupendous rotation. The physics of the ergosphere shows that if a mass approaching the event horizon is broken in two, so that one piece falls into the black hole, then the other piece could exit the ergosphere with more energy than it started with. The black hole essentially donates some of its angular momentum to this mass, thereby increasing its energy. A recent suggestion is that energy could be harnessed from this process by breaking and recombining magnetic field lines in the ergosphere. This would cause infalling matter to be naturally split into two plasma flows, one of which would receive an energy boost from the black hole. The Penrose process could also impart energy to one of the particle-antiparticle pairs, sometimes called 'virtual particles', that produce 'Hawking radiation'. These matter and antimatter pairs are constantly being created and destroyed due to minuscule quantum fluctuations in the fabric of space-time.

Another possibility, called the 'Blandford-Znajek process', uses an external magnetic field to extract the rotational energy of a rotating black hole. Here, the black hole is acting like a massive conductor spinning in the magnetic field of its accretion disk. The magnetic field lines are dragged around the black hole causing them to eject jets of plasma in opposite directions. This is believed to be the process that creates the energetic plasma jets seen in 'quasars'.

Although the engineering required for any of these possibilities is far beyond our current capabilities, the physics suggests that energy generation from black holes could reach 150 per cent efficiency, far greater than any energy-generation method currently used on Earth. ***AG***

GETTY X2 ILLUSTRATIONS: PETE LAWRENCE, DANIEL BRIGHT

EXISTENTIAL CRISIS OF THE MONTH...

HACKERS ARE MONITORING MY EVERY MOVE THROUGH MY PHONE

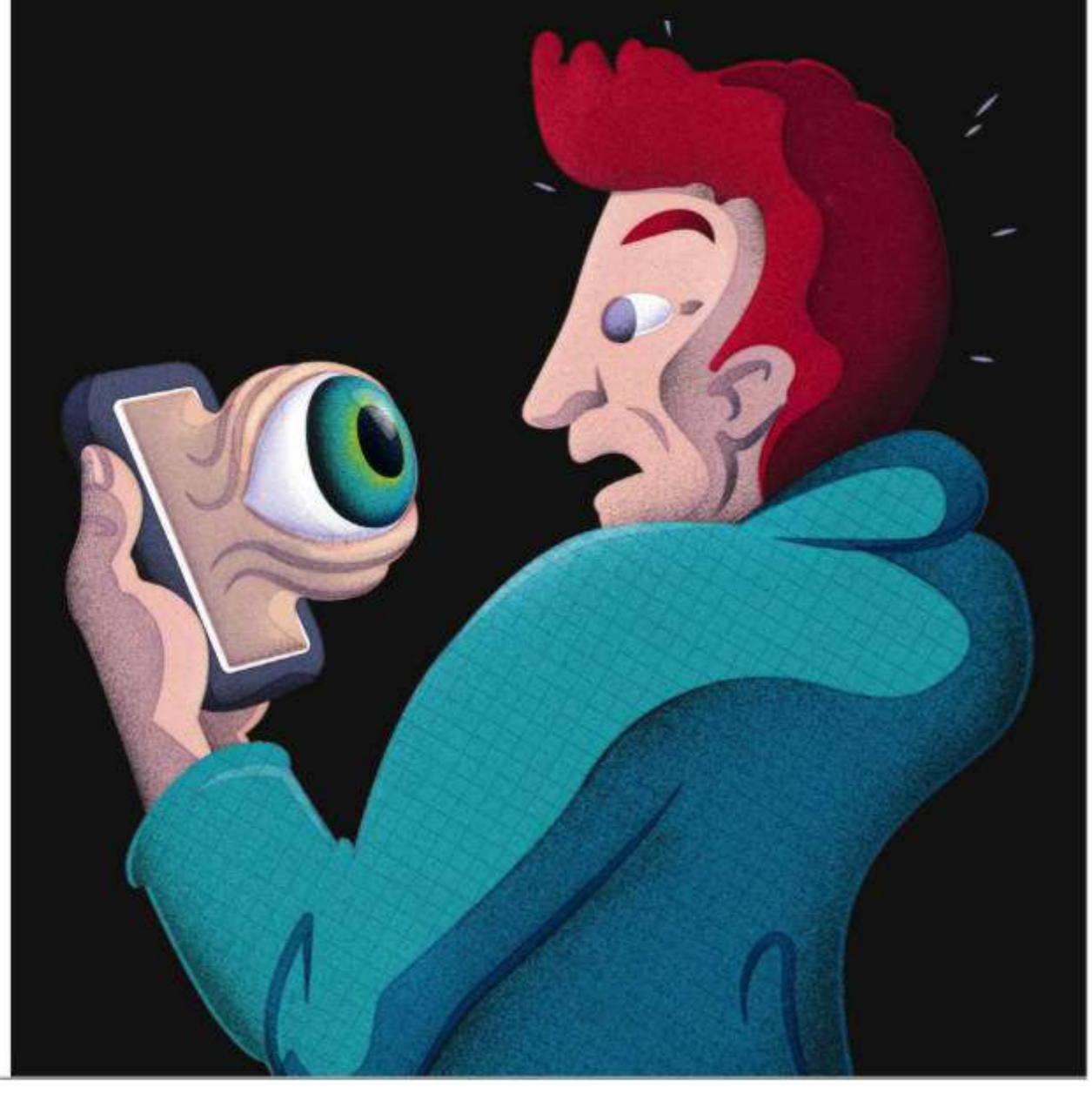
Nearly a decade ago, an Israeli technology firm called the NSO Group, run by former members of the Israeli Intelligence Corps, created mobile phone spyware software called Pegasus. Classed as a weapon, the Israeli Ministry of Defense licenses the export of Pegasus to foreign governments. Recently it has been discovered that this spyware has been used by many countries to infect the phones of activists, journalists and political leaders.

The spyware software is extremely clever, using multiple vulnerabilities in different apps on your phone. It may be installed by clicking on a link, but most insidiously it could even infect modern iOS iPhones through a simple iMessage with no clicks needed. Once infected, it provides access to your passwords, location, text messages, call and app data, and even the microphone and camera.

Pegasus is not the only spyware out there; we know of many more used by intelligence services or criminal organisations. Some malware or spyware is so clever that even performing a factory reset, which should wipe all apps and data, does not work – upon restarting, the phone is immediately reinfected.

You might get clues that your iPhone has been infected if your battery drains quickly when not in use, the screen turns on by itself without notifications, location services reports that your camera has used your location recently for no apparent reason, or you find a strange deleted photo that you never took.

In reality, we live in a connected world. If a powerful organisation really wants to hack your devices, they probably can. *PB*



ABDULLAH RIZWAN, KIDDERMINSTER

CAN ANY ANIMALS PHOTOSYNTHESISE?

Photosynthesis is a really efficient way of making nutrients. Instead of wasting time finding, eating and digesting food, plants use solar power to transform carbon dioxide and water into oxygen and sugars. The plant generates fuel for itself, and air for us to breathe. The magic happens inside specialised organelles, called chloroplasts, which contain the green photosynthetic pigment chlorophyll.

To answer your question, some animals have managed to harness the power of photosynthesis. For example, when sacoglossan sea slugs chow down on photosynthetic green algae, chloroplasts from the algae become incorporated into the animals' gut cells where they continue to pump out nutrients long after the rest of the algae have been digested and expelled. It's a feat called 'kleptoplasty'.

Other animals, including some clams and flatworms, also use the photosynthetic powers of algae, but adopt a symbiotic approach where the algae remain unharmed. Corals are the classic example. Most reef-building corals contain colonies of algae, called zooxanthellae, which live in their tissues and bequeath the coral their hue. During the day, the algae provide the coral with most of their energy needs and, in return, the algae get a safe place to live with a stunning sea view.

The only vertebrate animal known to harness solar power is the spotted salamander. Here, water-dwelling algae colonise salamander eggs shortly after they are laid, then become incorporated into embryonic cells where they help to feed the developing animal from within. Experiments reveal that embryos with more algae survive better and develop more quickly than embryos with fewer algae.

All of which begs the question, could we humans ever photosynthesise? Even if we could crowbar working chloroplasts into our cells (which we can't) and precisely alter our genomes to control them (which we can't), we still don't have a big enough surface area to volume ratio to generate the energy we'd require to live. Put simply, humans just aren't leaf-shaped! ***HP***

CROWDSCIENCE

Every week on BBC World Service, *CrowdScience* answers listeners' questions on life, Earth and the Universe. Tune in every Friday evening on BBC World Service, or catch up online at **bbcworldservice.com/crowdscience**

MARY COLLINS, BEDFORD

WHY IS HUMAN SKIN SO RUBBISH?

Skin is so versatile and adaptable that scientists are developing lab-grown skin grafts to deliver drugs – such as insulin to treat diabetes – directly into the body. Researchers hope these gene therapy skin grafts could one day treat a range of diseases. *CA*

If you've ever tripped and grazed your skin, broken out in a rash, or suffered from acne or eczema, you might have found yourself wondering why human skin is so frail and fragile. Bruises, dry skin, callouses, hives, sunburn and scar tissue are among the many skin ailments that can at best irritate us and at worst seriously harm our health. But these gripes are minor when we consider all the things skin does for us.

Skin is the largest and fastest-growing organ in the body. It provides a waterproof yet breathable barrier that protects us from the elements, parasites and pathogens. It is strong, yet extremely flexible. It helps regulate body temperature, reduces water loss and manufactures vitamin D. And, although it sometimes produces scar tissue, skin is amazingly good at self-healing after damage.

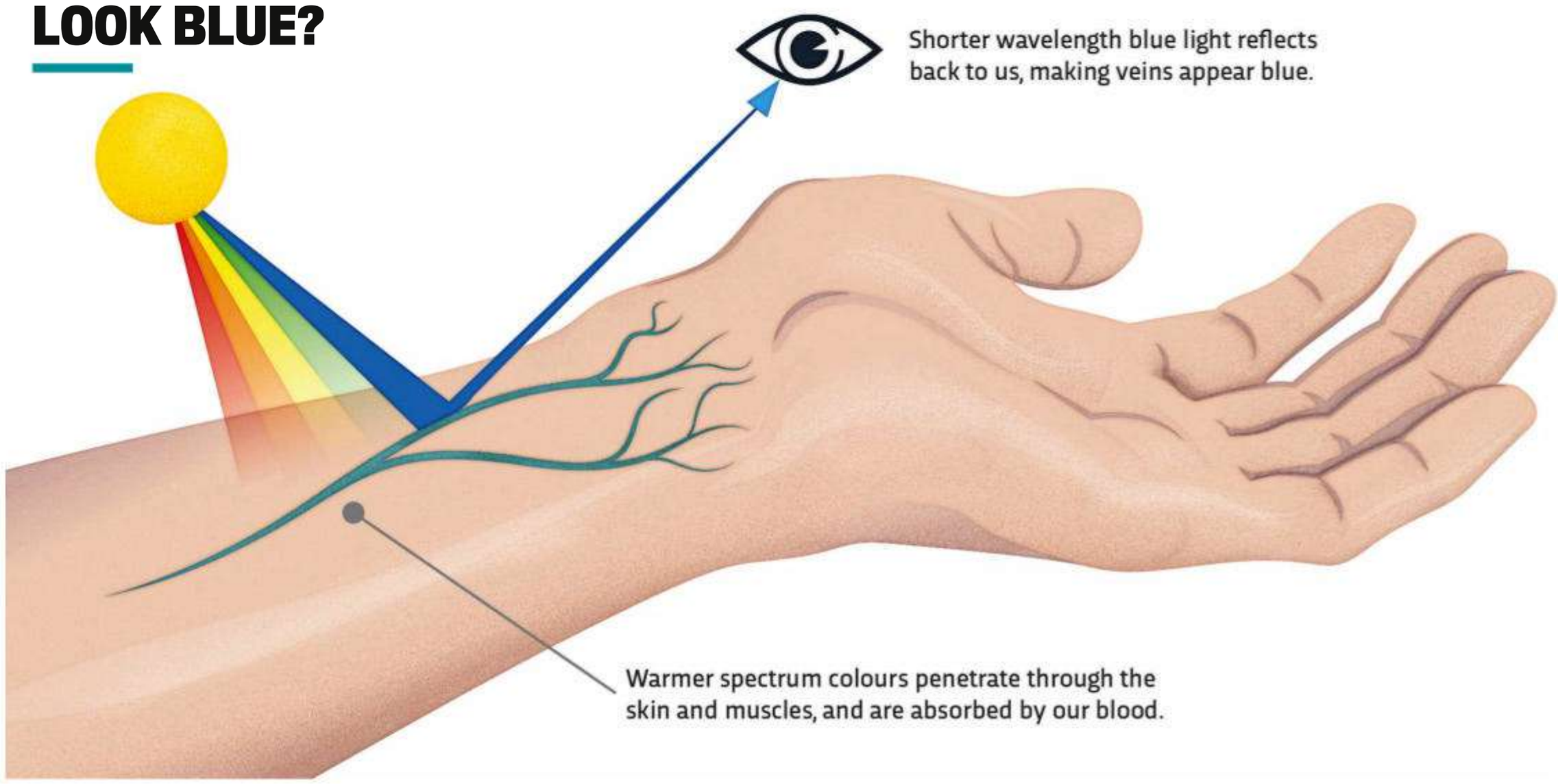
Humans are the only 'naked' ape and our unique skin adaptations have been crucial to our evolution. For example, without hair to protect us, human skin evolved melanin to block harmful UV radiation. Specialised sweat glands helped our ancestors thermoregulate while walking long distances in hot conditions, and the high density of nerve cells in our hands may have proved crucial for our ancestors to shape and use tools.

Humans can sweat from pores like this one, allowing us to stay cool in the heat

ALAMY, SCIENCE PHOTO LIBRARY, GETTY IMAGES ILLUSTRATION: DANIEL BRIGHT

SUSANNAH JENKINS, INVERNESS

WHY DO OUR VEINS LOOK BLUE?


Shorter wavelength blue light reflects back to us, making veins appear blue.
Warmer spectrum colours penetrate through the skin and muscles, and are absorbed by our blood.

Your blood gets its colouration from red blood cells, which contain haemoglobin – iron-rich molecules that are bright red when carrying oxygen and a darker, duller red when deoxygenated. So why, when you look at the veins in your arm, do they appear to be blue? The answer lies in the fact that different colours of light have different wavelengths, so they are absorbed and reflected differently when they hit our skin.

Red light has a very long wavelength, so it can travel through the skin relatively easily and is absorbed by the haemoglobin in the blood. Blue light, on the other hand, has a much shorter wavelength and so it is mostly reflected by the skin. If you shine white light – a mixture of all the different wavelengths – onto your arm, where veins are present, the red light will be absorbed and the blue light will be reflected. This means that the light returning to your eyes will contain more blue than red wavelengths, making the veins look blue compared to the surrounding skin.

Medics sometimes make use of this phenomenon by shining a red or infrared light on the skin to help them locate a vein to administer an injection. Similarly, nightclubs sometimes use blue lights in the toilets to discourage intravenous drug use, by making it hard to see veins through the skin. ***CA***

ALEJANDRA LOPEZ, BRIGHTON

HOW MANY BIRDS ARE STRUCK BY WIND TURBINE BLADES?

As wind energy has grown in popularity, reports of birds killed in collisions with moving turbine blades have become more common. Few studies have investigated the phenomenon, but estimates suggest that between 10,000 and 100,000 birds are killed by turbine blade strikes annually in the UK. That's a lot, but it's worth noting that approximately 55 million birds are killed in the UK each year by domestic cats. Nevertheless, research suggests there may be ways to make wind turbines safer for wildlife. For example, a small-scale study in Norway found that painting one blade black reduced bird deaths by 70 per cent. ***CA***

DEAR DOCTOR...

HEALTH QUESTIONS DEALT WITH BY *SCIENCE FOCUS* EXPERTS

BEN SIMPSON, LEICESTER

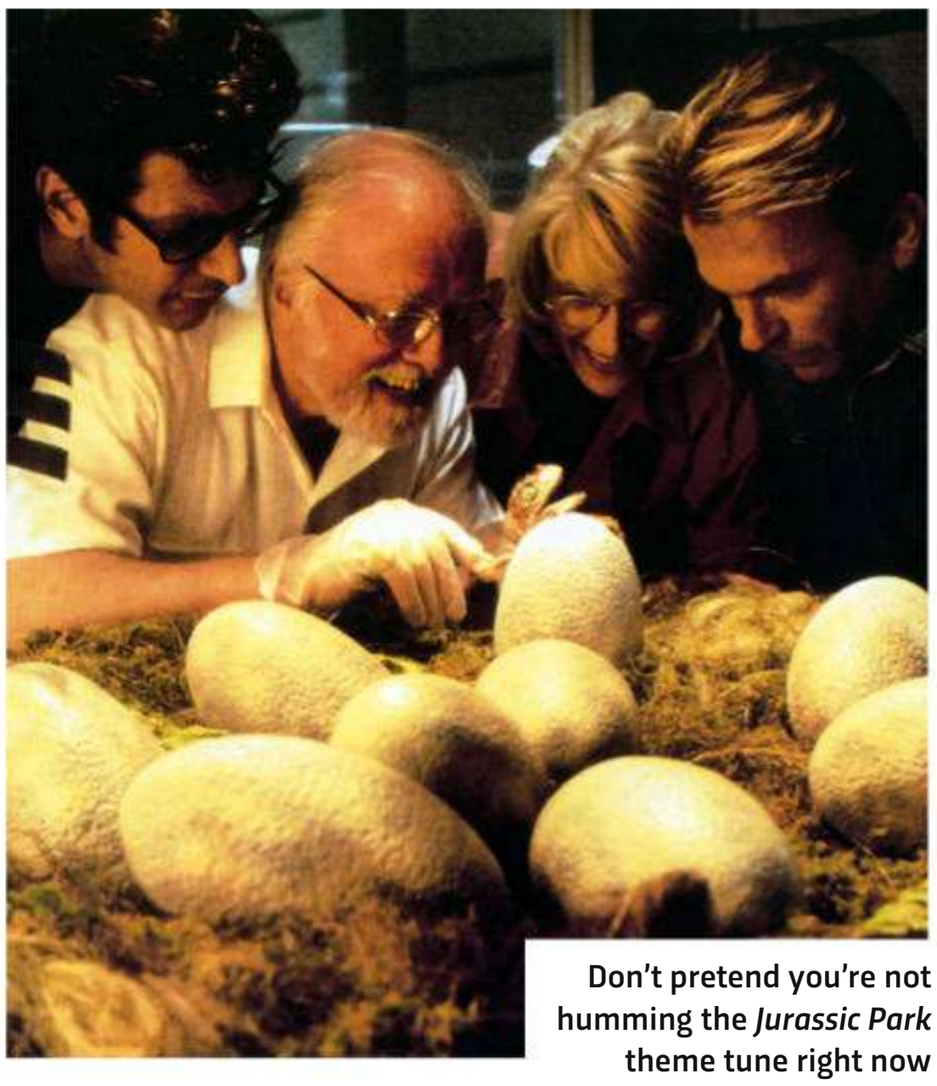
I WORK IN CUSTOMER SERVICE. WHY IS BEING POLITE ALL THE TIME SO EXHAUSTING?

Being polite at work when you don't feel like it is similar to any situation in life that requires you to make the effort to mask your true feelings. That could be feigning gratitude for that revolting meal your partner just spent hours making for you, or putting on a brave smile for the birthday socks from your aunt that you really didn't want. As you say, it's exhausting, especially if your job means you have to do it all day long. In a work context, psychologists call it 'emotional labour', which involves either 'surface acting' – concealing your true feelings – or 'deep acting'. The latter means altering your actual underlying feelings, which can be achieved by various means, such as reappraising the scenario. For example, by taking the perspective of an irate customer and so genuinely sympathising with their situation. Due to the effort and emotional regulation involved, both forms of emotional labour can be tiring. But there's some evidence that the deep acting version is better for the employee and customers – probably because it's more convincing and it creates a virtuous feedback loop in which the employee is rewarded by their customer's satisfaction, such as a smile or a tip. ***CJ***

ANNABEL HALLIGAN, NORWICH

DOES HUMAN BODY TEMPERATURE IMPACT GLOBAL WARMING?

Humans typically radiate around 100W of heat, equivalent to an incandescent light bulb. In a confined space, people's body heat can raise the ambient temperature, but on a global scale this effect is negligible, especially compared to the vast amount of heat energy the planet receives from the Sun, for example. In general, global warming is not caused by heat sources on Earth, but rather by greenhouse gases in the atmosphere which prevent heat (mostly from the Sun) from dissipating into space. As humans, we therefore have a far greater impact on the climate through burning fossil fuels and therefore creating greenhouse gases than we do from our body heat. ***AFC***



Don't pretend you're not humming the *Jurassic Park* theme tune right now

TIM PRICE, WREXHAM

HOW LONG DID IT TAKE DINOSAUR EGGS TO HATCH?

As far as we know, all dinosaurs reproduced by laying eggs. Some species, like the giant long-necked sauropods, laid dozens of eggs in a small nest, which they essentially abandoned and left to hatch on their own. Others, like the feathered raptors closely related to birds, laid a smaller number of larger eggs, and actively sat on their nests to provide protection.

But how long did it take dinosaur eggs to hatch? Until recently, palaeontologists had no idea.

A study published by Dr Gregory Erickson and colleagues answers this question for two particular dinosaurs: the duck-billed herbivore *Hypacrosaurus* and *Protoceratops*, a horned dinosaur closely related to *Triceratops*. By studying the growth lines in the microscopic teeth of embryos found inside fossilised eggs, Erickson and his team determined that *Protoceratops* eggs took about 2.8 months to hatch, while those of *Hypacrosaurus* incubated for 5.8 months. Modern-day reptiles incubate their eggs for a similar period of time – often many months. Birds, on the other hand, hatch very quickly, usually within two months, and sometimes even within two weeks. Today's birds descended from dinosaurs, but they must have evolved their hyper-fast hatching rates much more recently. ***SB***

QUESTION OF THE MONTH

CALLUM REID, SUNDERLAND

WHAT WOULD HAPPEN IF ALL VOLCANOES ON EARTH ERUPTED AT ONCE?

There are about 1,500 potentially active volcanoes around the world. To a scientist though, a volcano counts as active if it has erupted in the last 10,000 years and only around 550 have erupted in recorded history. But the exact number is much less important than their size. Eruptions are classified using the Volcanic Explosivity Index (VEI). A VEI of 1 results in at least 10,000m^3 of material flung into the air, and each successive number corresponds to 10 times more ejected material. The largest eruption ever recorded was Mount Tambora in 1815, with a VEI of 7. The explosion could be heard 2,600km away and more than 160km^3 of material was thrown into the atmosphere. This single volcano caused temperatures in the northern hemisphere to drop by 0.5°C for six months, as dust blocked out the Sun. The year 1816 was dubbed 'the year without a summer' and, combined with disrupted rainfall patterns, caused harvests around the globe to fail.

That was one volcano. There are 32 known VEI 7 or VEI 8 volcanoes and if they all erupted at once it would easily be an extinction-level event for the majority of living things, including humanity. The initial eruptions would cause most aeroplanes in the air to crash, collapse buildings in the western USA, South America, southern Europe and the Far East, and cause power grids to fail across most of the developed world. Drinking water supplies would be rendered toxic by ash, global temperatures could fall by 15°C for six months, and acid rain would make agriculture impossible for the next decade.

Luckily, this is almost guaranteed never to happen. Volcanoes are driven by localised upwellings of magma beneath the Earth's crust. Every volcano erupting simultaneously would be like every bubble in a fizzy drink breaking the surface at once. ***LV***

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WINNER

The winner of next issue's *Question Of The Month* wins a **Kindle Kids**, worth £99.99. Purpose-built for reading, with a glare-free display and weeks of battery life, it includes a two-year worry-free guarantee and a kid-friendly case. Enhanced browsing and search means kids can locate titles without the exact spelling.

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THE EXPLAINER

WHAT'S THE DIFFERENCE BETWEEN A HEADACHE AND A MIGRAINE?

WHAT'S THE DIFFERENCE BETWEEN A HEADACHE AND A MIGRAINE?

Headache is a neurological symptom, the underlying cause needs to be established. Migraine is a genetic, neurological condition often causing headache, but is also associated with many other symptoms including heightened sensitivity to light, sound, movement and smells, as well as dizziness, brain fog, abdominal pain, speech difficulties, visual disturbances, nausea, vomiting, fatigue and irritability. But this list is not exhaustive. Migraine is a spectrum condition so some people have infrequent, mild attacks, while others have more severe, frequent episodes. Some suffer daily impact from the effects of migraine on their brain.

WHAT HAPPENS DURING A MIGRAINE?

During migraine attacks, neurochemicals trigger a wave of electrical depolarisation at cell surfaces, known as 'cortical spreading depression', which spreads out over the brain. The effects of neurochemical disturbances may vary from person to person, from attack to attack, and throughout a person's life.

'Aura' are neurological disturbances during the hour before the headache hits, and affect about a third of sufferers. Aura are often visual with zigzag lines, flashing lights, blurred vision or blind spots. In the next phase, symptoms such as headache, 'brain fog' and fatigue can occur. Cognitive problems are common. The vagus nerve, which runs from the brain to the gut, is also affected. This slows down the emptying of the stomach, which can lead to nausea and sometimes vomiting, and delays absorption of helpful medications and may prolong attacks.

Pain during a migraine attack may be felt anywhere on the head, neck or shoulders. Abdominal pain is common in children.

SHUTTERSTOCK, SCIENCE PHOTO LIBRARY, GETTY IMAGES X2

HOW CAN YOU MANAGE A MIGRAINE?

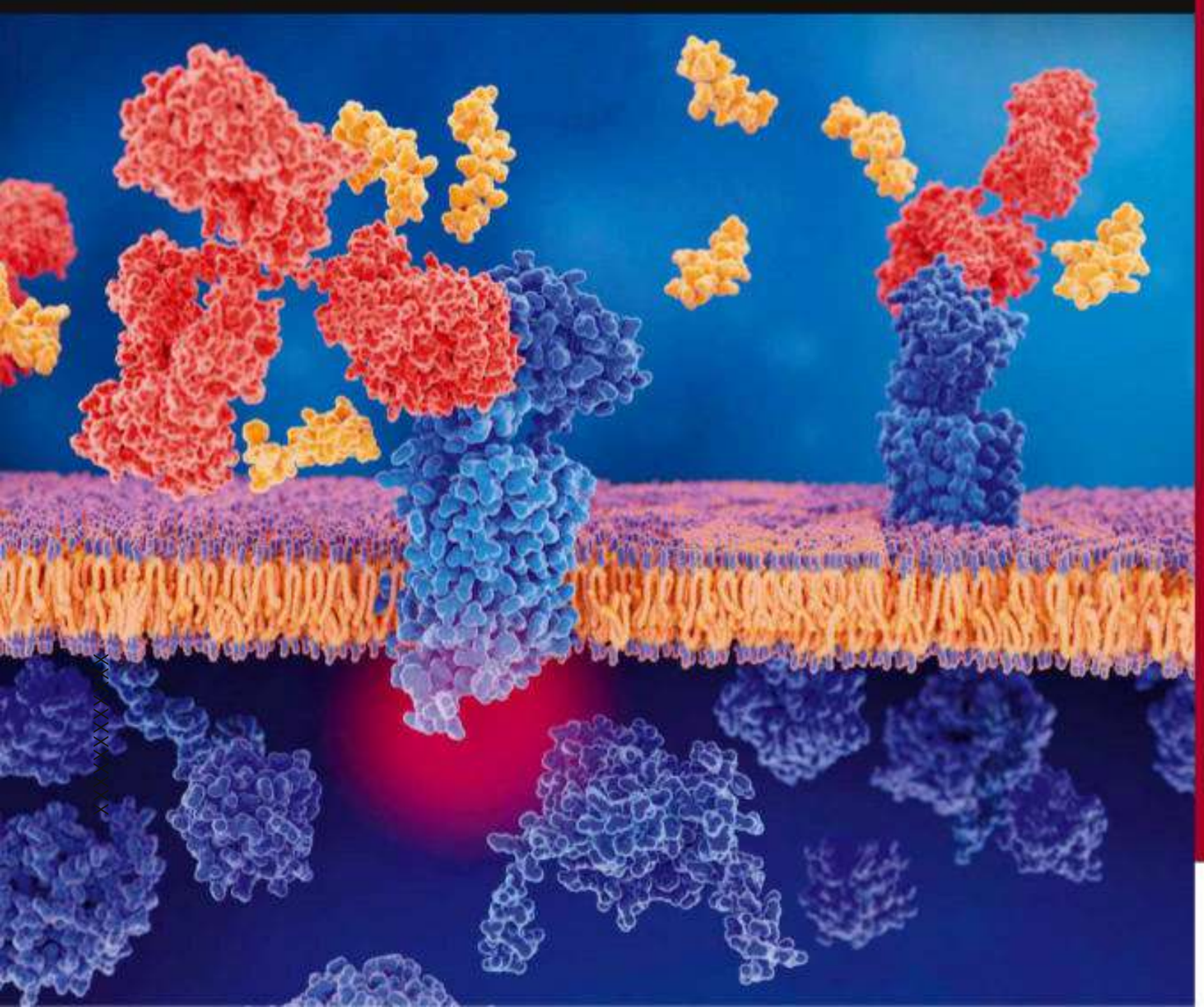
People hunt for that one thing they can do to stop attacks. They eliminate certain foods, stop caffeine and alcohol, searching for the key to switch off attacks. Sadly, it is not that simple. But you can try to keep track of what changes in the 48 hours before an attack. Using a simple headache diary may help identify some things to control in future and limit attack impact.

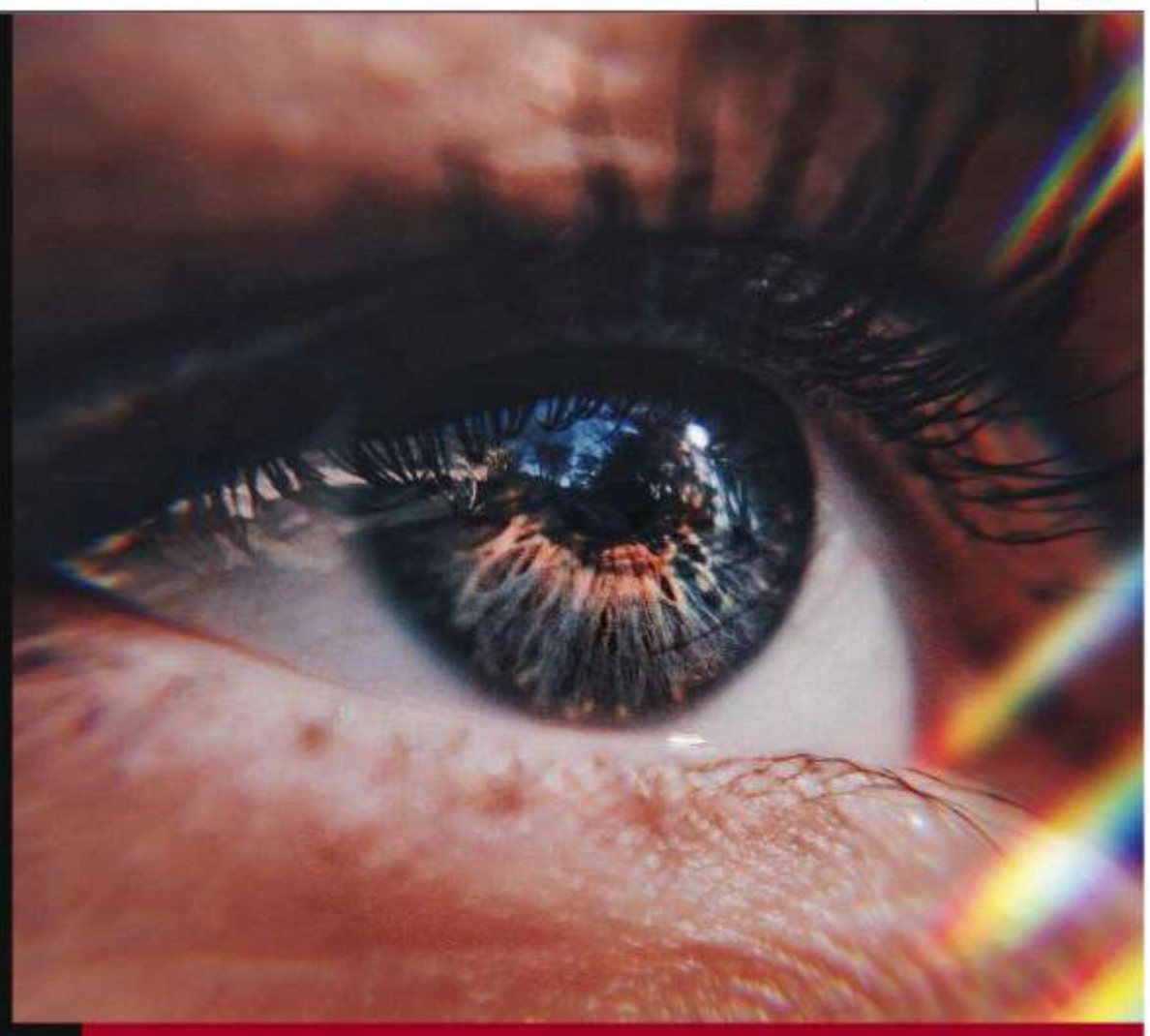
Diagnosis is on the history of symptoms. A migraine family history helps confirm the diagnosis, but is not essential and often unknown for various reasons.

Effective treatment requires the right medication in the right place at the right time. When a migraine attack starts to roll, it gathers momentum much like a snowball rolling down a mountain. Treating early is crucial, and discussing with a GP or headache specialist which combination of medications will suit you is so important.

Often a simple anti-nausea medication with a painkiller will help if taken early enough, but it may be necessary to add in migraine-specific medications called triptans. There are seven currently available. If one does not suit you, try a different one. The effect of each varies from person to person. These should not be taken on more than 10 days in the month, as overuse of acute migraine medication aggravates the brain. Avoid codeine and opiates which can quickly worsen migraine.

If you get more than about five attacks per month, explore preventive methods. There are many available, including supplements, medications, neuromodulation devices and injections. The newest are anti-Calcitonin Gene Related Peptide (CGRP) self-administered injections. CGRP is a pain neurochemical implicated in triggering attacks in some people. These monoclonal antibody injections block either CGRP neuropeptides, or receptors on cells. They can be extremely effective in reducing migraine attacks.





WHAT CAUSES MIGRAINE ATTACKS?

Migraine genes set the brain to be less able to process sensory inputs and make the brain vulnerable to attacks. But that is not the whole story. Epigenetics, the interaction of genes with our behaviours and environment, is important too. The more the brain is challenged by these stimuli, the more pain neurochemicals are produced. Migraine threshold theory suggests that combinations of changes irritate the brain and trigger attacks once pain neurochemicals reach a certain level.

'Change' is a key word. The migraine brain is more sensitive to internal body changes, such as blood sugar levels, sleep routines, hormones or stress, and external environment factors – light glare, strong visual patterns like stripes, stuffy air quality, and even weather.

Some things seem to be particularly likely to lead to attacks. Skipping meals leading to fluctuating blood glucose levels is one. Regular snacking may help. People with migraine are often sensitive to carbohydrates though, so low GI foods are preferable. Broken or extended sleep can aggravate attacks – this is especially hard for teenagers, who wake early for school but then lie in at weekends.

Hormones have a major role. Many teenagers have worsening attacks during the turbulent hormonal times of puberty, with growth spurts and menstrual cycles contributing. Many women find they have more attacks with their period and during the perimenopause. Oestrogen levels change erratically before periods stop completely and often for some years afterwards.

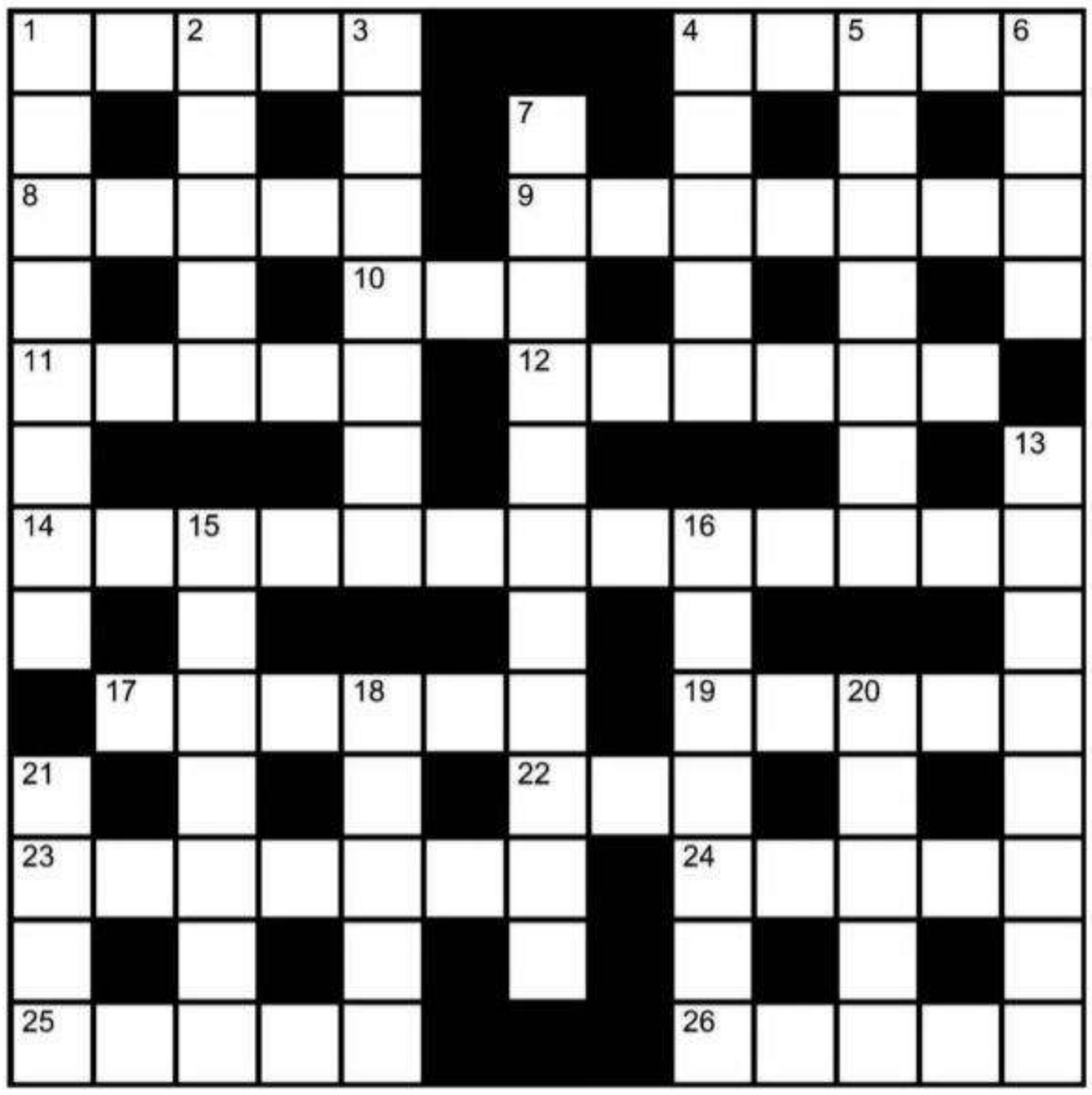
Any type of change can lead to attacks worsening – a new job, moving house, travelling abroad. But so can stress reduction. 'Let-down' or weekend migraine attacks are commonly described – frustrating for people relaxing after a stressful time.

by DR KATY MUNRO

Katy is a GP headache specialist at the National Migraine Centre. She hosts the podcast Heads Up, *and is the author of* Managing Your Migraine *(£9.99, Penguin Life).*

CROSSWORD

GIVE YOUR BRAIN A WORKOUT



ACROSS

1 I would put trophy first, being a matchmaker (5)
4 Pity he's running around in the morning (5)
8 Imagines not starting a lot of paper (5)
9 Bird to overhaul part of house (7)
10 Beam at a fish (3)
11 Father not arranging entertainment (5)
12 Panic a Russian outside, being a doomed flier (6)
14 He arranges steps to charge her poor performance (13)
17 Drunkard gets swine a plug (6)
19 The Spanish show respect in the joint (5)
22 A record peak (3)
23 Liked living in extremity, having turned up (7)
24 Digit hard to get into apple, say (5)
25 Parade takes thirty-one days (5)
26 Sound in estuary is heard (5)

DOWN

1 Shell vehicle at a fast rate (8)
2 Current scheme to go round is unattractive (5)
3 Doctor is coming in with award for strip (7)
4 A pie's changed colour (5)
5 Every character I married by hut – new angle (7)
6 Hence in another gondola (4)
7 Good beginning for a plane (6,5)
13 Personnel kiss in style (4,4)
15 Performing daily, in theory (2,5)
16 It paces around when sterilised (7)
18 Mogul chased around ravine (5)
20 Boat uncovered, having guile, initially (5)
21 Second woman to get unwanted mail (4)

ANSWERS

For the answers, visit **bit.ly/BBCFocusCW**
Please be aware the website address is case-sensitive.

GETTY IMAGES

NEXT ISSUE

BLUE LIGHT EXPLAINED

PLUS

THE WINTER SOLSTICE

Will Christmas be cancelled this year? Who knows. In the meantime, feast your eyes on some winter traditions from around the world.

2021 NEWS ROUNDUP

It's been a strange year.

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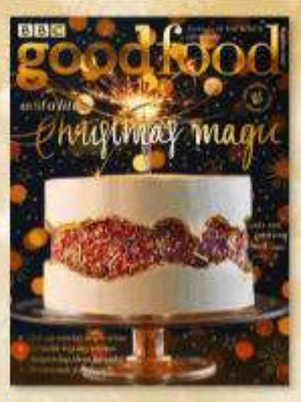

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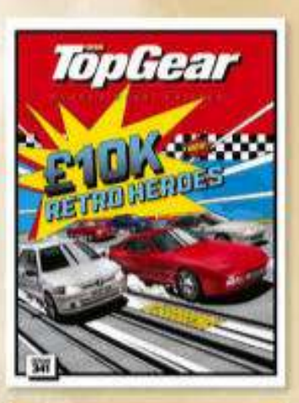

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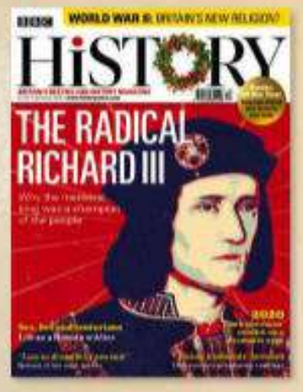

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POPCORN SCIENCE

Do ghosts exist?

Should we get Venkman and co. on speed dial?

by **STEPHEN KELLY**

If there's something strange, in your neighbourhood, who ya gonna call? Probably the police, because neither ghosts nor the Ghostbusters are real. But that doesn't stop people believing in the paranormal. A YouGov poll in 2019 found that 45 per cent of Americans believe in ghosts, whereas in 2016 another YouGov poll showed that British people are more likely to have faith in spooky spirits than the existence of God. With the release this month of nostalgic sequel *Ghostbusters: Afterlife*, there seems no better time to ask: why are we still haunted by our belief in ghosts?

"It tends to be driven by two things," says Richard Wiseman, Professor of the Public Understanding of Psychology at the University of Hertfordshire. "One is personal experience – lots of people claim to have had a paranormal experience after the loss of a loved one. The other is popular media. Most experiences aren't that difficult to rationalise away. With photographs, for example, there used to be many double exposures but not so many today. Those sorts of ghosts have gone away with the arrival of camera phones."

According to Wiseman, both drivers take advantage of various psychological traits – some of which are universal, while others are specific to certain people. "Humans have open, imaginative minds," he says. "And we want to imagine a world that doesn't have pain or suffering, where our loved ones are still with us. We're pattern-searching creatures. And the price we pay for seeing patterns that are there, is occasionally going into overdrive and seeing patterns that aren't there."

More specifically, Wiseman links a belief in ghosts to creativity. In 2013, for example, a study performed at the University of British Columbia concluded that people with a higher tendency to attribute human traits to non-human objects (anthropomorphising) were also more likely to believe in ghosts. "People who believe in a lot of these things do have the same kind of psychological make-up," says Wiseman. "They're open-minded, creative, quite high in ability to be absorbed in a situation like a play or a film, to identify patterns."

This innate creativity can be taken advantage of, however. A study performed in the 1990s by psychologist Dr James Houran found that people are more likely to believe in the paranormal if they've been 'primed'. This is a psychological term for when the introduction of a stimulus influences a subsequent stimulus, for instance how seasoning changes the taste of a steak.

"He took two groups of people around a disused cinema," explains Wiseman. "He told one group it was an architectural tour and they experienced nothing anomalous. He told the other it was haunted and, lo and behold, some people in the group started to experience things. When there's ambiguity, suggestion can tell you how to perceive, and how to report what you're experiencing. Magicians and psychics use it all the time."

The immense power of human belief, its ability to colour and shape how we experience reality, can often lead to us believing silly things (like ghosts) and sinister things (like conspiracy theories). But Wiseman chooses to celebrate the optimistic side of this double-edged sword.

"If you look at the great scientific advances, like putting someone on the Moon or coming up with a vaccine for COVID in months, to do that you have to believe you can do something that's pretty close to impossible. I think that capability to believe in something, even though the evidence is minimal, allows us to do amazing things. And every once in a while, ghosts lead us astray. But you can't have one without the other. It's the price we pay for doing amazing things." **SF**

VERDICT

Nope, no point in calling the Ghostbusters, because ghosts simply don't exist.

by **STEPHEN KELLY** *(@StephenPKelly)*
Stephen is a culture and science writer, specialising in television and film.

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When polar ice melts, it harms habitats as far away as Asia and Africa. In 2022, conservationist (and Christopher Ward Challenger) Tom Hicks will lead an expedition to the North Pole to measure ice melt rates for the David Shepherd Wildlife Foundation (DSWF). On his wrist will be the C60 Anthropocene GMT. Able to monitor two time zones at once, waterproof to 600m and with a sapphire dial that recalls polar ice, it can withstand whatever the Arctic throws at it. And with five percent from the sale of each watch going to DSWF, it's playing its own part in the fight against climate change.

christopherward.com

Christopher Ward

Ingeniously English.
Unsurprisingly Swiss.

AN IMPORTANT MESSAGE FROM PROFESSOR NICK LEMOINE MD PHD FMEDSCI, CHAIR OF THE MEDICAL RESEARCH FOUNDATION

Gifts in Wills could be the key to protecting the future of human health

Our experience of COVID-19 shows how suddenly a global health challenge can appear. As someone interested in science, you will understand that while nobody can predict what we will face next, we can be certain that the future will bring many more threats to human health.

As Chair of the Medical Research Foundation – the charitable arm of the Medical Research Council – I have seen the incredible impact that individuals who remember the Foundation in their Wills can have on the future of our health and wellbeing here in the UK. These gifts fund research and researchers which can have far-reaching implications for human health.

With a gift in your Will you can play a key role in providing the science that will protect the health of future generations.

Right now, the Foundation is funding research to tackle antimicrobial resistance, and investing in researchers like Dr Myrsini Kaforou – who will make the fight against antimicrobial resistance her life's work.

Without support at the crucial early stages, researchers like Dr Kaforou can be forced to abandon their passion and leave science altogether, with an immeasurable loss to future human health. Gifts in Wills provide the long term funding and security that allows the Foundation to invest in projects like Dr Kaforou's and lay the foundations for quality research in years to come.

Your Will can fund the rational response to health

> **"As scientists, our duty is to secure the future of research for the generations that follow."**
>
> Professor Fiona Watt, President of the Medical Research Foundation and Executive Chair of the Medical Research Council.

challenges that medical science provides.

While we don't know what the future holds for human health in the UK, we do know that research, and the brilliant scientists driving that research forward, are the key to meeting those challenges for years to come.

"The funding I received through the Medical Research Foundation will be transformative for my research." Dr Myrsini Kaforou

But many of these scientists rely on the generosity and foresight of fellow members of the medical community who understand the power of science and are willing to leave a gift to medical research in their Wills. At the Medical Research Foundation, over 90% of our voluntary income comes from individuals who choose to include a gift in their Will – they are crucial in the Foundation's ability to fund research that will enable the next generation of scientists to make real world discoveries in the future.

I firmly believe that a gift in your Will to the Medical Research Foundation is an excellent investment and will have a lasting impact on science and on the future of human health in the UK.

Please consider this very special gift today.

Professor Nick Lemoine MD PhD FMedSci
Chair of the Medical Research Foundation

Get your free guide to supporting research in your Will.

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Medical Research Foundation

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